CHAPTER 4.5 TREND ANALYSIS

The Office of Water Quality Monitoring and Assessment (WQMA) operates an ambient monitoring network which is designed to measure long term water quality trends. The design of the trend network is such that key water quality variables are measured at targeted locations approximately every month. The WQMA trend network began in August of 1967 and since that time 275,984 collections have occurred at 454 individual stations. For the purpose of this report we are limiting our analysis to 436 active trend stations that contain sufficient data during the 20-year period from 1991 to 2010. These data, therefore, represent the most recent period of any long-term changes that may be occurring. The most recent data have the best quality control documentation and therefore a higher level of assurance. These data were also collected and analyzed using more modern methods and instrumentation that have better sensitivity, precision, and accuracy. Finally, for those trend stations that have stream discharge rates as one of the water quantity variables, we are able to match daily average discharges with daily water quality samples. Matching flow with water quality indicators allows for the detection of flow adjusted trends and permits the calculation of annual loadings expressed in pounds.

Trend stations are divided into three categories based on water body types: free-flowing stream, lake or reservoir, and tidal estuary. Further subdivisions of the stream and estuarine stations help to identify network priorities based on program types. For example, a main subdivision of the trend network is focused on the Chesapeake Bay. Within the Bay Program there is a collection of 39 core stations, all in estuarine waters extending from tidal fresh to polyhaline, 7 core plankton stations in mesohaline and oligohaline tidal waters, 34 non-tidal free-flowing freshwater streams, and 7 Potomac embayment estuarine stations.

Figure 4.5-1 shows the locations of all trend and gauge stations.

Methodology

The statistical method used in this report consists of a modified seasonal Kendall nonparametric procedure (WQ3). For a full discussion of the statistical methodology please refer to Chapter 2.4 – 4 "The Seasonal Kendall Trend Analysis Method" in the 2006 Integrated Report available at: http://www.deq.virginia.gov/wqa/ir2006.html. Trends attaining 90% confidence were considered statistically significant (very likely to be occurring), trends attaining < 90% but ≥75% confidence were considered likely to be occurring, and the remaining results were classified as either no change or insufficient data.

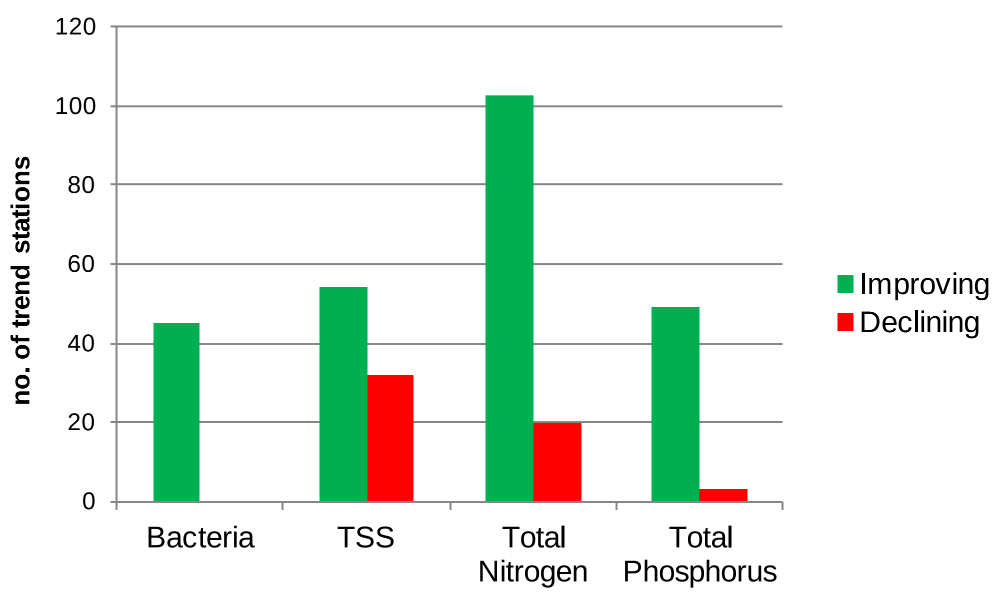
The analysis was extended to determine the annual percent change over the period of record to better represent the results when presented on maps. Annual percent change was calculated over the 20-year time period using the WQ3 linear regression slope and intercept output and the parameter value at the beginning of the period as reference. Combined trend results in high resolution maps for all stations can be viewed at: BACTERIA_MAP.pdf, NITROGEN_MAP.pdf, PHOSPHORUS_MAP.pdf, and SUSPENDED_SOLIDS_MAP.pdf. Station metadata and linear regression results are available at: GIS_SAS.xlsx

Summary

Over the past twenty years the ambient water at the Commonwealth's long-term monitoring stations have experienced a 14% overall improvement in quality when considering the four key indicators. The most salient finding is that there have been no statistically significant declines in water quality for bacteria over the last twenty years. Improvements for bacteria occurred at 10% of the stations, nitrogen improved at 24% and declined at 5%, phosphorus improved at 11% and declined at 1%, and suspended solids improved at 12% and declined at 7%. During this time period, the population in Virginia increased from 6,187,358 to 8,001,024, an increase of almost 30%, suggesting that some pollution control measures have been able to track increasing development.

A summary of the trend analysis counts is provided in the table and chart below.

PARAMETER	TREND	ALL	ALL%	LAKE	ESTUARY	RIVER	FLOW ADJUSTED
Bacteria	declining	0	0.0%	0	0	0	0
Bacteria	improving	45	10.4%	1	13	20	20
Bacteria	other	386	89.6%	13	133	243	86
Nitrogen	declining	20	4.6%	2	1	14	11
Nitrogen	improving	103	23.6%	8	33	67	23
Nitrogen	other	313	71.8%	13	112	185	75
Phosphorus	declining	3	0.7%	0	0	2	2
Phosphorus	improving	49	11.2%	0	16	15	22
Phosphorus	other	384	88.1%	23	130	249	85
Suspended Solids	declining	32	7.3%	1	12	10	11
Suspended Solids	improving	54	12.4%	2	21	26	14
Suspended Solids	other	350	80.3%	19	113	230	84



Stream Gauge Network Flow-Adjusted Trends

The Virginia Department of Environmental Quality (DEQ) operates 106 trend stations in association with stream gauges. Most of the stream gauging stations are operated by the U.S. Geological Survey (USGS) or by DEQ, with a few others operated by several local authorities. Real-time data from many of these stream network gauges are available from the USGS at: http://waterdata.usgs.gov/va/nwis/rt. For trend analyses, stream discharge or flow in cubic feet per second was reduced to daily and monthly averages for two purposes. The daily average values were paired directly with daily instantaneous water quality measures so that flow-adjusted and loading trends could be calculated. The absolute flow is not necessary for determining flow-corrected water quality trends; the relative flow is sufficient. Therefore, it was possible to determine flow-corrected trends for several water quality trend stations in proximity to one stream gage. Loading trends based on flows and concentrations were derived only for those trend stations collocated with gauging stations.

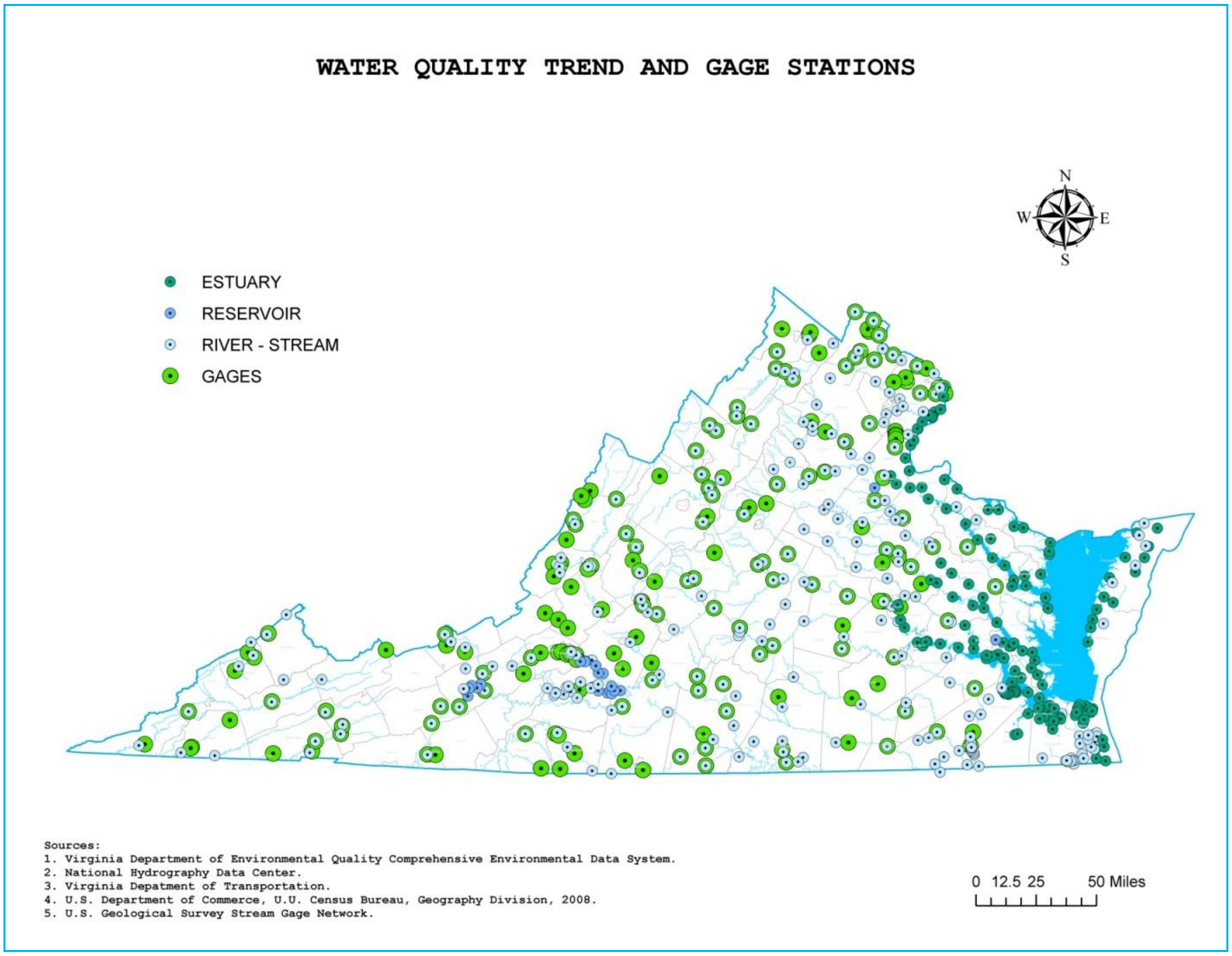
Three DEQ trend stations required special consideration when flow was applied. The trend station 1BNFS000.57, located at the DGIF Boat Launch downstream of the Rt. 340 bridge on the North Fork of the Shenandoah River, required the flow data from USGS gauge 01634000 N F SHENANDOAH RIVER NEAR STRASBURG to be summed with the flow from USGS gauge 01635500 PASSAGE CREEK NEAR BUCKTON, VA. Likewise the trend station 6ARSS014.15, on Russell Fork off RT. 80 AT POOL POINT, is below USGS gauge 03208500 RUSSELL FORK AT HAYSI, VA and USGS gauge 03209000 POUND RIVER BELOW FLANNAGAN DAM. The Jackson River trend station 2-JKS000.38, at Route 220 Iron Gate, was flow-corrected by subtracting the flow at USGS gauge 02016000 COWPASTURE RIVER NEAR CLIFTON from USGS gauge 02016500 JAMES RIVER AT LICK RUN. We considered adding the flow from the 02037500 James River Kanawha canal to the 02037000 James River Huguenot station at trend station 2-JMS117.35; however, the discharge from the canal appeared to be influenced over time by control structures. Furthermore, the flow diverted into the Kanawha canal is a very small percentage of the overall James River flow and was not expected to have any influence on the overall loading calculation for the downstream portion of the James River. Personal observations also indicate that the Kanawha canal flow at times ceases to return to the mainstem James.

Several DEQ ambient trend stations were close enough to real time stream gauges that flow correction could be applied. The stream gauge at USGS 02025500 JAMES RIVER AT HOLCOMB ROCK, VA was applied to DEQ trend stations 2-JMS270.84, 2-JMS275.75, 2-JMS279.41, and 2-JMS282.28. At the suggestion of the DEQ Blue Ridge Regional Office, gauge USGS 02061500 BIG OTTER RIVER NEAR EVINGTON, VA was applied to calculate flow-adjusted trends at stations 4ABOR000.62 and 4ALOR014.75.

See table: FLOW_STATIONS.xlsx

The monthly average flows derived from the instantaneous values were used to determine if an actual trend in the flow variable was occurring at each gauging station during the period of interest. The instantaneous measurements were obtained from the USGS Instantaneous Data Archive web site at: http://ida.water.usgs.gov/ida/. Trends in flow were evaluated at 116 gauging stations. This number included several gauges not directly associated with trend stations, but that were of interest due to their proximity to DEQ trend stations. Only seven that were directly associated with water quality trend stations revealed a statistically significant trend with 90% confidence; see Table FLOW.xlsx. Figure 4.5-2 WQ3 Modified Seasonal Kendall Graphic Outputis the graphic output from WQ3 for the Roanoke River stream gauge at route 746 Watkins Bridge near Rand. The variable MAVG is the monthly average flow calculated from the USGS instantaneous data, which is recorded at fifteen minute intervals. The trend at this station shows a statistically significant decrease in discharge, (-37.72 CFS/yr, dependent $p = 0.091$.)

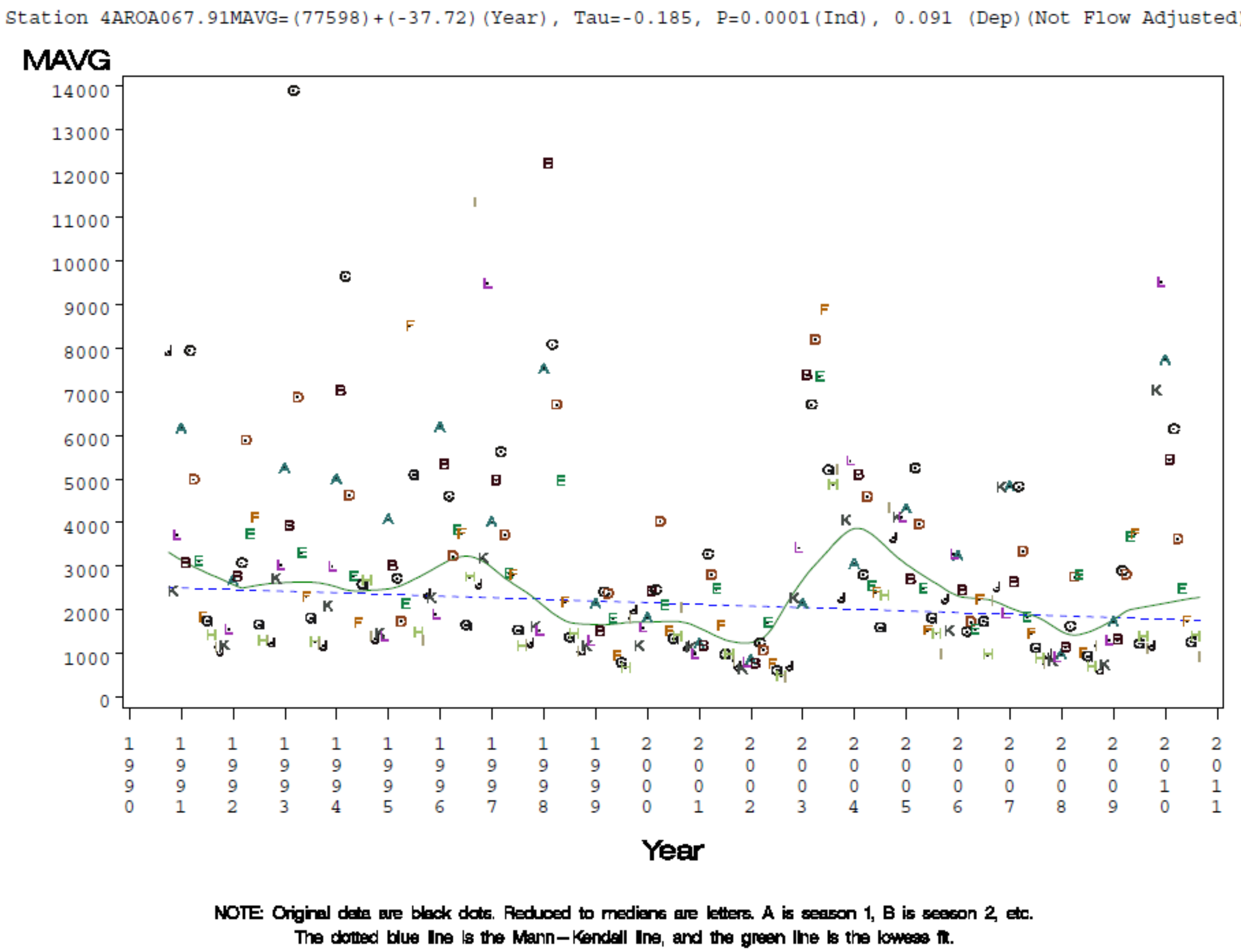
Figure 4.5-1 Trend and gage stations



Each letter in Figure 4.5-2 represents the average value for that season and year. The data were blocked into twelve seasons (A – L), with A representing January, B February and so forth. The entire WQ3 output for all trends in flow at all stations can be viewed from this link: FLOW.pdf

Statistically significant trends in the amount of water flowing in a stream may induce spurious trends in water quality variables. The key parameters are usually correlated with discharge rate, so changes in volume will affect the trends in these parameters. Reporting an improving change in water quality that does not account for changes in discharge may lead to spurious conclusions. Thus, water quality trends should be carefully evaluated where significant changes in flow occur.

Figure 4.5-2 WQ3 Modified Seasonal Kendall Graphic Output

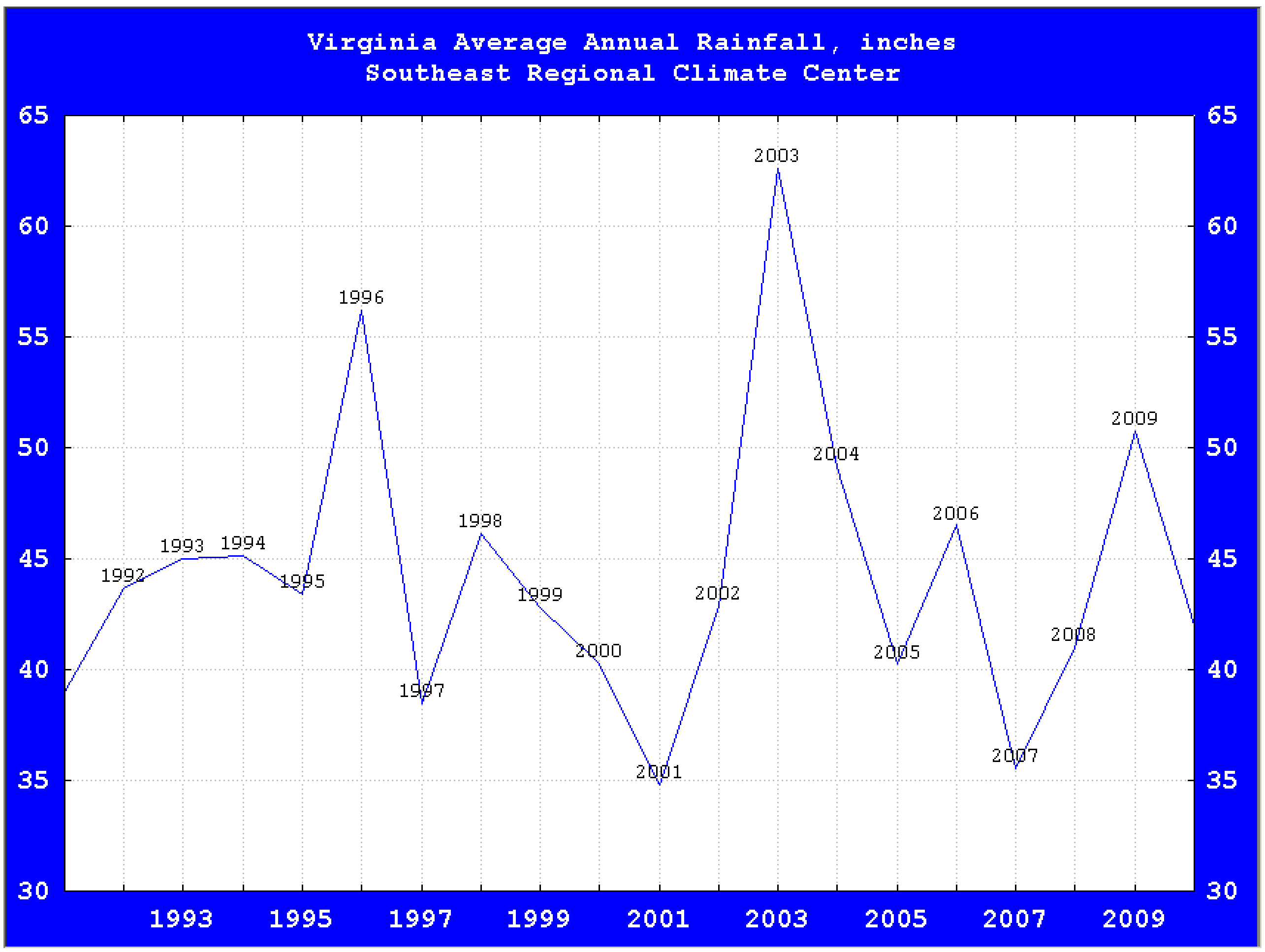


For specific examples, caution should be taken when interpreting the significantly declining trends for total suspended solids at trend station 2-APP110.93 (APPOMATTOX RIVER RT.45 BRIDGE AT FARMVILLE), total nitrogen at 2-BFL011.03 (BUFFALO CREEK Rt. 658 Bridge), total phosphorus, and suspended solids at 4ABOR000.62 (BIG OTTER RIVER ROUTE 712 BRIDGE), and bacteria, total nitrogen, phosphorus, and suspended solids at 4ALOR014.75 (LITTLE OTTER RIVER RT. 718 BR ABOVE BEDFORD STP OUTFALL).

Of special interest is the number of gauges statewide showing a downward trend, negative *tau*. Regardless of the statistical methodology used, if no trends were occurring, it would be expected that about half the analyses would have positive *taus* and the other half would be negative. Of the 116 stations analyzed, 106 had negative *taus* (decrease in flow), four stations had *taus* of zero, and six showed positive trends (increasing flow). This strongly suggests a general pattern of declining discharge (reduced flow) statewide that may be a result of declining precipitation. Inspection of the graphs of discharge versus time (see FLOW_ADJUSTED_TRENDS\FLOW.pdf.) reveals a similar, repetitious pattern among the many stations for which the analyses were conducted.

Despite these indications of reduced preciptation, the pattern in flow over the most recent twenty-year time period indicates two wetter than average periods, the first in 1996-97 and the second in 2003-04, as shown in Figure 4.5-4 North River Flow at River Mile 14.08, Shenandoah Basin. The 2003 annual rainfall in Virginia, 62.63 inches as recorded by the Southeast Regional Climate Center at the University of North Carolina (http://www.sercc.com/), was the highest ever recorded since records began in 1895. The 1996 rainfall, at 56.19 inches, was the second highest amount ever recorded. The state's average annual rainfall between 1895 and 2010 was 42.76 inches and between 1991 and 2010 was 51.06 inches, as shown in Figure 4.5-3 Virginia Precipitation. Figure 4.5-4 North River Flow at River Mile 14.08, Shenandoah Basin illustrates the pattern of flow seen in the vast majority of stations analyzed in this manner. The three-year drought during the years 2000-2002 should be noted. This twenty-year pattern in flow is less pronounced in the southwestern Tennessee and Big Sandy basins.

Figure 4.5-3 Virginia Precipitation



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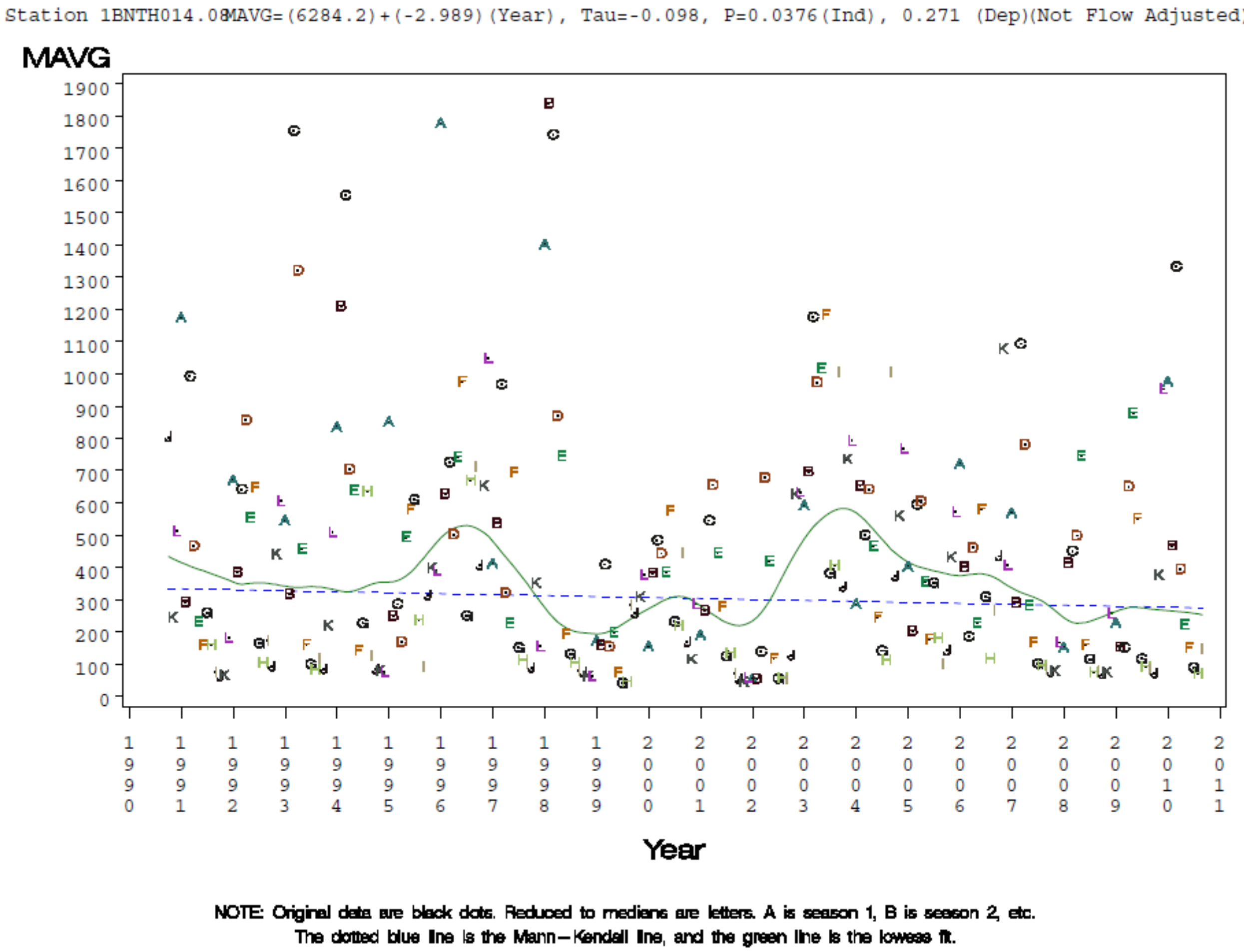
Notice in Figure 4.5- the green line which represents the LOWESS (locally weighted scatter plot smoothing) of the monthly average flows (CFS) and how there are noticeable increases in 1996 and 2003.

Figure 4.5-4 North River Flow at River Mile 14.08, Shenandoah Basin



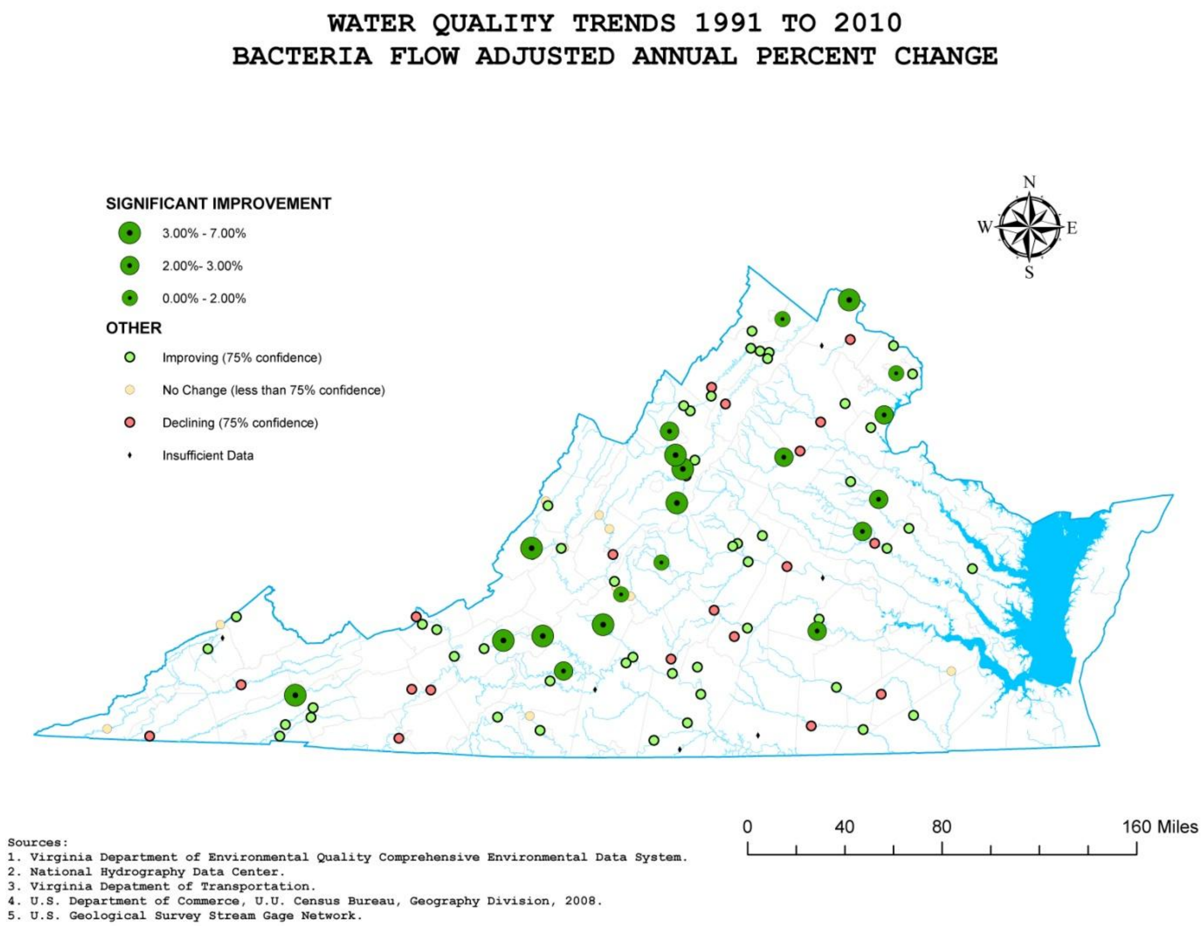
Discussion

The trend analyses focused on four key water quality indicator variables, bacteria Colony Forming Units per 100 ml (BACT), total nitrogen mg/L (TN), total phosphorus mg/L (TP), and total suspended solids mg/L (TSS) - refer to spreadsheet trend_flow.xlsx. These variables were selected because together they represent the most common causes of water quality degradation (bacteria, nutrient enrichment, and sedimentation), and the interpretation of changes in their concentrations are never ambiguous; increases in any one of the four are always interpreted as a decline in water quality. The data contained in this spreadsheet is direct output from WQ3 and includes descriptions for each variable in the comment block of the variable heading. Among these stations there were 110 significant trends detected with flow-correction and 114 without flow-correction. The use of flow-correction in this analysis marks an improvement over the trend results presented in the 2006 Integrated Report, which did not account for discharges.

Bacteria-Flow Adjusted

Water quality as indicated by concentration of bacteria has improved in the last twenty years at flow adjusted stream locations. One-hundred seven (107) water quality stations with matching flow were analyzed for flow adjusted trends, twenty of which showed significant declines in counts of bacteria. Not a single station of the 107 showed a significant increase. Percent improvements ranged from 1.7% to 6.4% annually. Please refer to Figure 4.5-5 Bacteria, Flow-Adjusted.

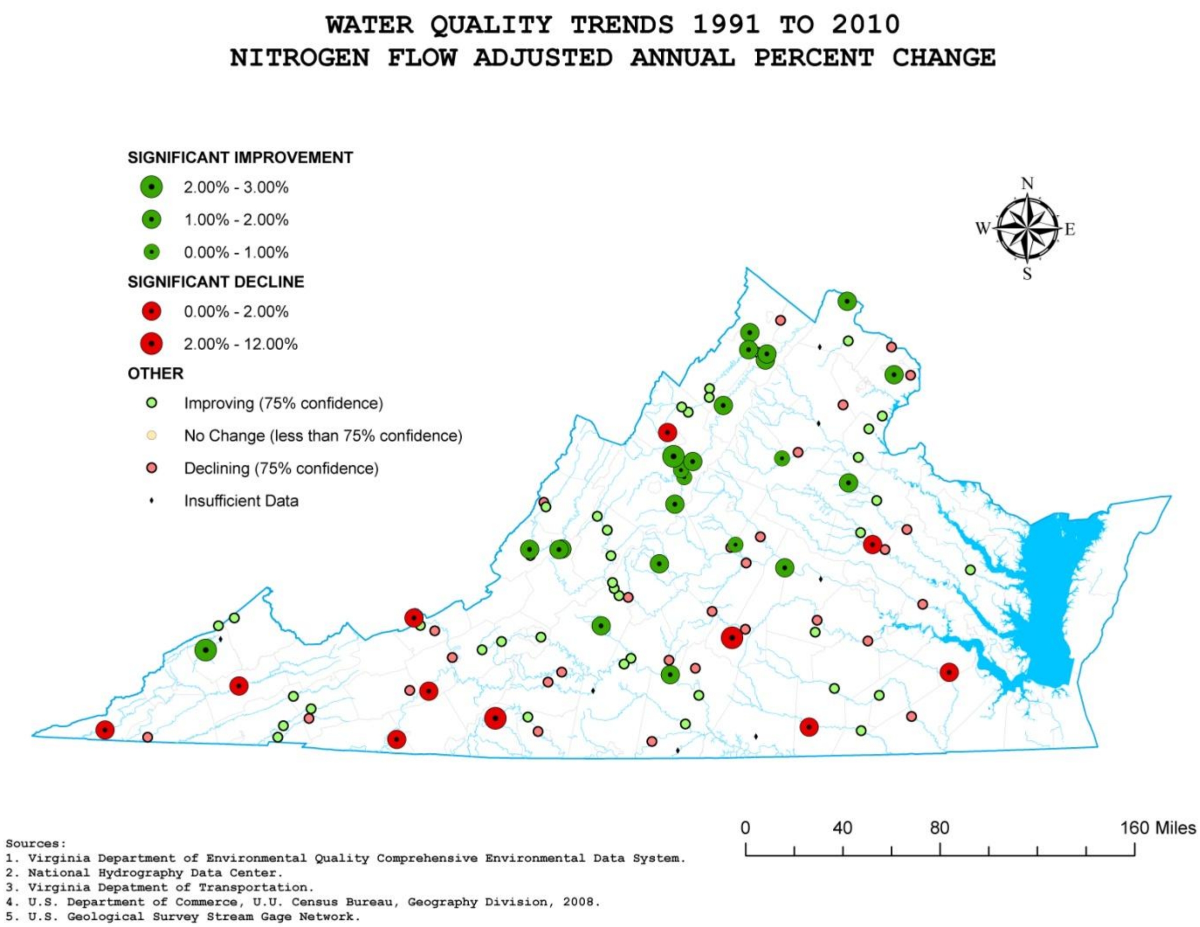
Figure 4.5-5 Bacteria, Flow-Adjusted



Nitrogen-Flow Adjusted

One-hundred ten (110) water quality stations with matching flow were analyzed for total nitrogen trends; 23 showed significant improvements and 12 had significant declines in water quality. Improvements ranged from 0.8% to 2.5% annually while declines ranged from 0.4% to 12%. Please refer to Figure 4.5-6 Nitrogen, Flow-Adjusted.

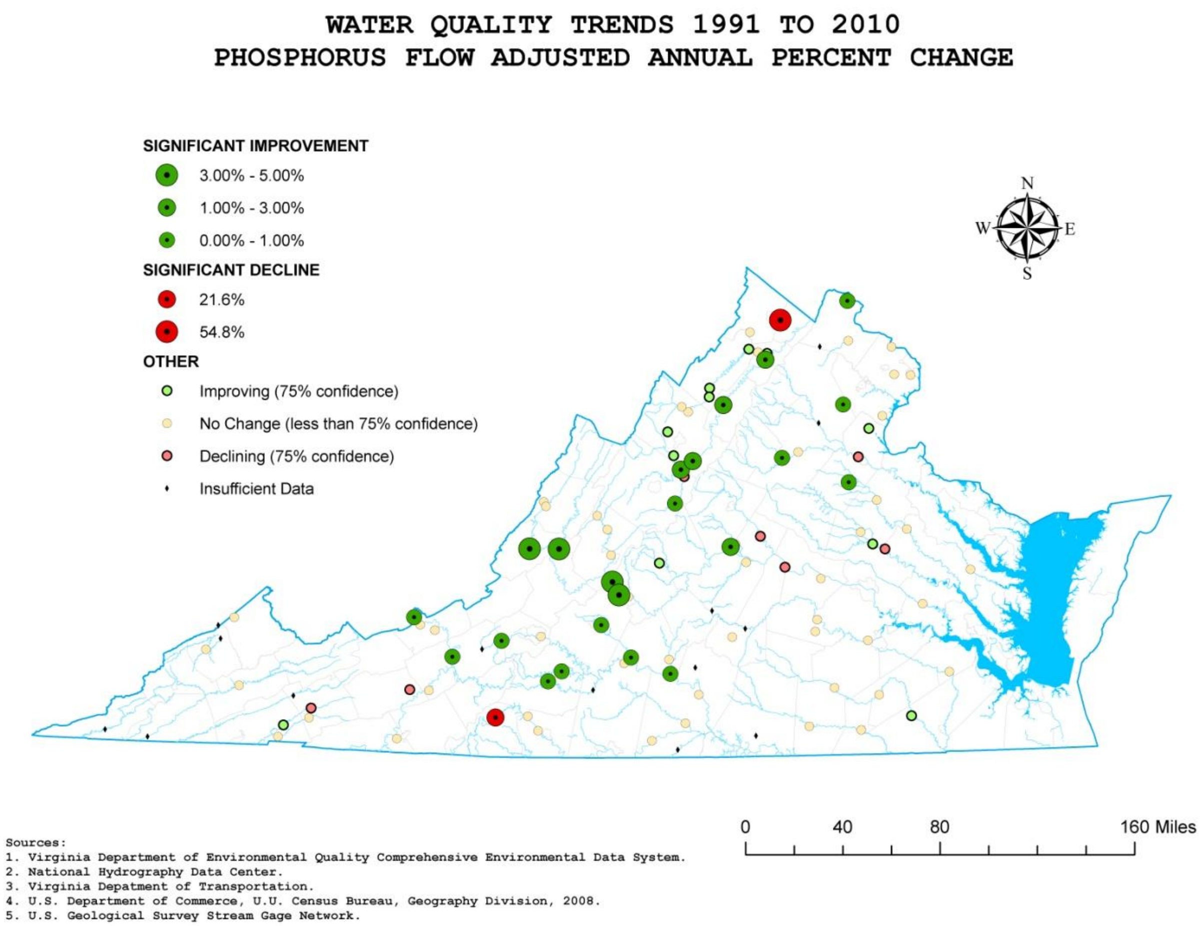
Figure 4.5-6 Nitrogen, Flow-Adjusted



Phosphorus-Flow Adjusted

Water quality for phosphorus has improved in the last twenty years at flow-adjusted stream locations. One-hundred nine (109) water quality stations with matching flow were analyzed for total phosphorus trends; twenty-two showed significant improvements while only two stations had significant declines in water quality (1AOPE036.13 - OPEQUON CREEK RT. 655 BRIDGE and 4ASRE075.69 - SMITH RIVER RT. 708 BRIDGE). Improvements ranged from 0.0% to 5.2% annually while the two declines were 22% and 55%. The slopes for these two declining stations were 0.01 mg/L per year and 0.02 mg/L per year respectively which indicate a small increase in concentration. Please refer to Figure 4.5-7 Phosphorus, Flow-Adjusted.

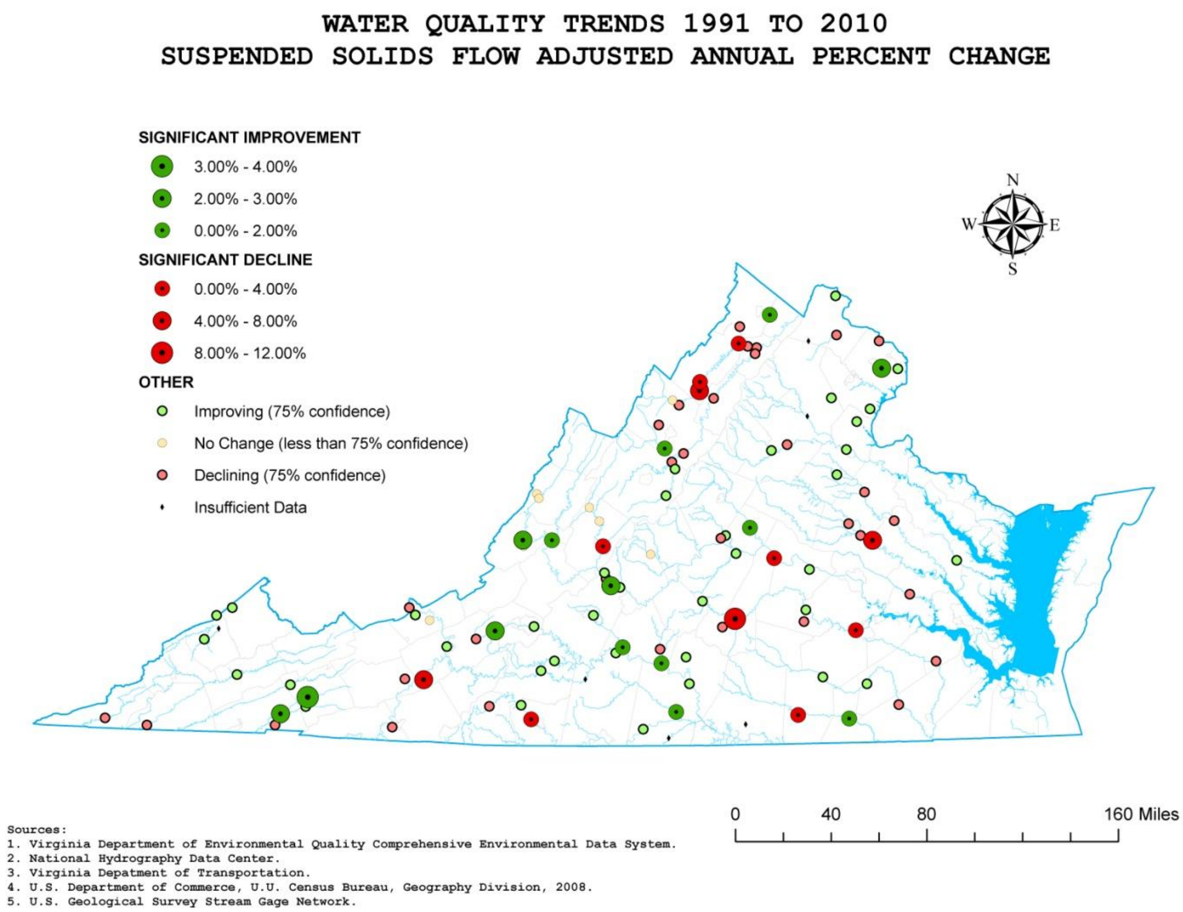
Figure 4.5-7 Phosphorus, Flow-Adjusted



Suspended Solids-Flow Adjusted

One-hundred nine (109) water quality stations with matching flow were analyzed for flow-adjusted total suspended solids; fourteen stations showed significant improvements in water quality ranging from 1.2% to 3.2% annual change, and 11 stations had significant declines ranging from 1% to 10% annual change. Please refer to Figure 4.5-8 Suspended Solids, Flow-Adjusted.

Figure 4.5-8 Suspended Solids, Flow-Adjusted



Noteworthy stations that saw significant improving water quality in three of the four indicators are listed below. None showed improvements in all four parameters.

1AACO014.57 - ACCOTINK CREEK Rt. # 620 - BACT, TN, and TSS,

1ACAX004.57 - CATOCTIN CREEK Rt. # 663 - BACT, TN, and TP,

1BMDL001.83 - MIDDLE RIVER ROUTE 769 BRIDGE - BACT, TN, and TP,

1BNTH014.08 - NORTH RIVER RT. 693 at Quarry upstr of G.S. - BACT, TN, and TSS,

2-JKS000.38 - JACKSON RIVER RT. 727 IRON GATE - TN, TP, and TSS,

2-JKS023.61 -JACKSON RIVER JACKSON RIVER AT COVINGTON GAGE - BACT, TN, and TP,

2-JMS275.75 - JAMES RIVER BELOW BIG ISLAND - BACT, TP, and TSS,

3-ROB001.90 - ROBINSON RIVER Rt. # 614 (Locust Dale Rd) - BACT, TN, and TP,

4ALOR014.75 - LITTLE OTTER RIVER RT. 718 BR ABOVE BEDFORD STP OUTFALL - BACT, TN, and TP,

4AROA097.46 - ROANOKE RIVER ROANOKE R @ BROOKNEAL boat ramp - TN, TP, and TSS,

4AROA227.42 - ROANOKE RIVER RT. 773 AT GAGING STA. IN LAFAYETTE - BACT, TP, and TSS.

Only three stations had significant declines in two parameters and none had declines in three or more parameters.

4ASRE075.69 - SMITH RIVER RT. 708 BRIDGE - TN and TP,

5AMHN082.13 - MEHERRIN RIVER MEHERRIN R AT RT. 644, PENNINGTON BRIDGE - TN and TSS,

9-NEW107.51 - NEW RIVER STA #25 ALLSONIA - TN and TSS.

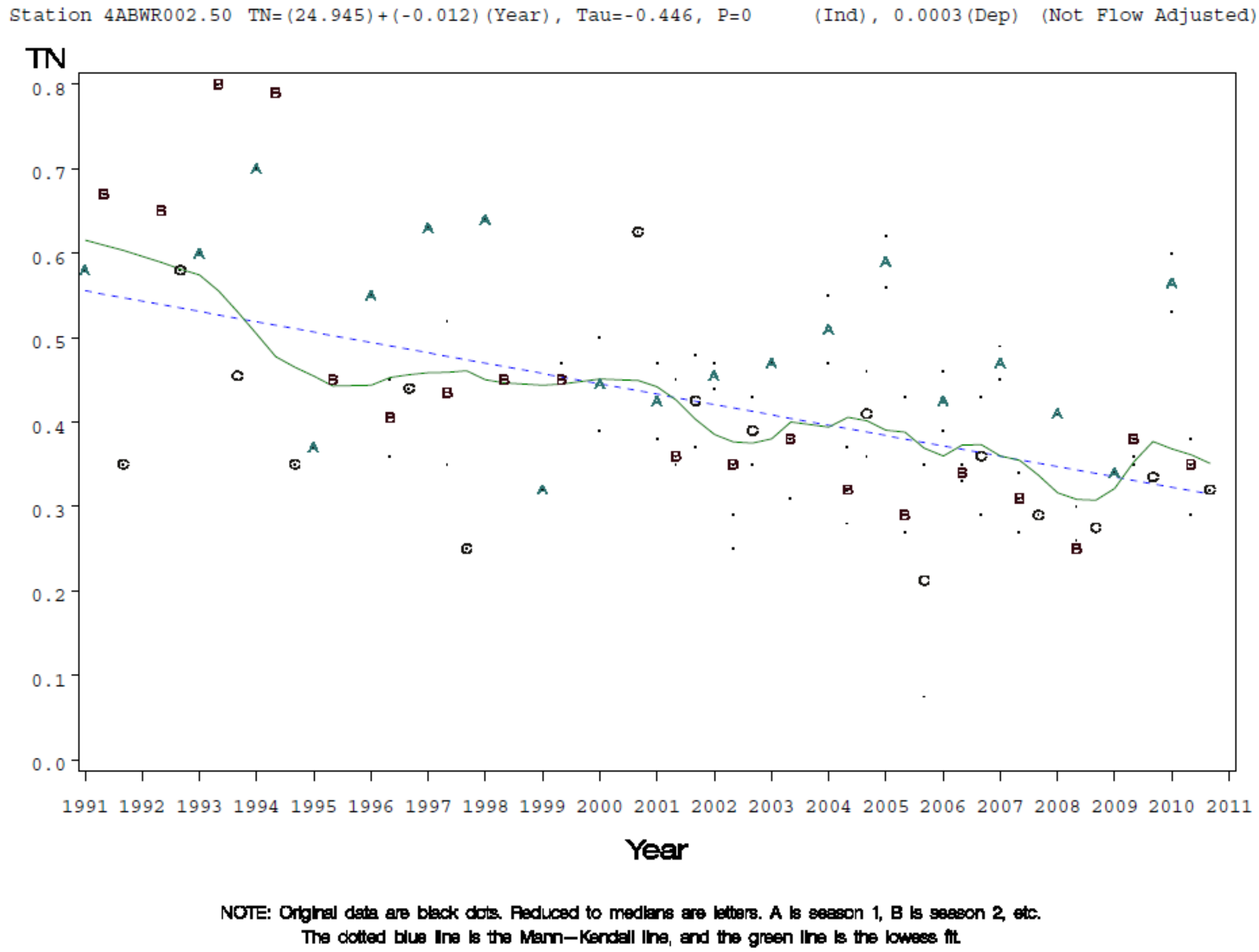
Lakes and Reservoirs

Since 2000 the state's major reservoirs have been monitored under a new program designed to better interpret lake water quality parameters in terms of recreational use. The main focus has been to sample only a few key reservoirs widely used by the public during the months of April to October. As a consequence of a shortened monitoring season, data were blocked into three time periods for analysis using the modified seasonal Kendall application. The three seasons used were Spring, Summer, and Fall with Spring - A represented by April and May, Summer - B included June, July, and August, and Fall – C included September and October. An example output is included for station 4ABWR002.50 BLACKWATER RIVER SMITH MTN LK in Figure 4.5-9. Notice the three seasons are identified by the black uppercase letters A, B, and C (Spring, Summer, and Fall respectively). Although the trend analysis period of record runs from 1991 to 2010, prior to the implementation of the new reservoir monitoring program in 2000 sample collection in some cases occurred year-round from 1991 to 2000. It should be noted that other reservoir monitoring not associated with key trend reservoirs still occurs, but on a rotating schedule.

<u>Results</u>

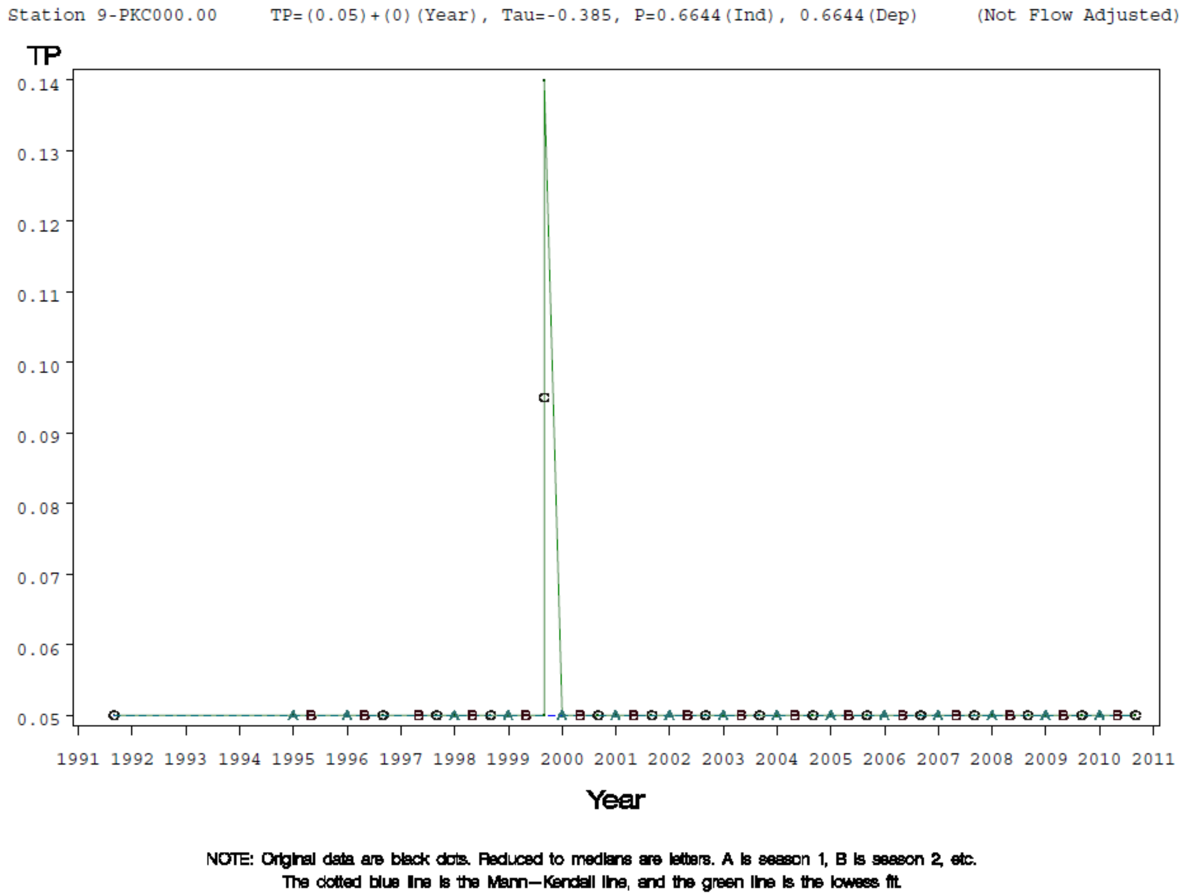
Only one reservoir station had a significant improvement in water quality for bacteria. Nitrogen showed significant improvement in water quality at eight stations and significant declines at two locations. Phosphorus improved at two locations. Suspended solids improved at two locations and declined at one. The statistical tabular results can be viewed at: LAKE.XLS and the graphical output is available at: LAKE.pdf.

Figure 4.5-9 Total Nitrogen (Improving Trend)



A large number of bacteria and phosphorus concentrations at these stations had measurements that were at the detection limit, which in turn limits the ability to detect significant changes in water quality, see Figure 4.5-10 Total Phosphorus Trend (Many Values at the Detection Limit (9-PKC000.00 PEAK CREEK CLAYTOR LK MTH OF PKC CREEK #4A TOP #4B).

Figure 4.5-10 Total Phosphorus Trend (Many Values at the Detection Limit)



Estuaries

Estuaries are defined in the DEQ water quality monitoring program as those stations that are tidal extending from tidal fresh to polyhaline. The trend network consists of 146 estuarine stations of which seven are Chesapeake Bay plankton monitoring stations, 44 Chesapeake Bay core stations.

DEQ does not maintain any water quality trend stations in the mainstem of the Chesapeake Bay or Atlantic Ocean, although water quality monitoring does occur on the mainstem Bay and in the Commonwealth's territorial oceanic waters.

Results

Bacteria conditions significantly improved at thirteen stations and there were no significant declines for bacteria. Nitrogen significantly improved at 33 stations and only one showed a significant decline which is a Chesapeake Bay core station on the Elizabeth River, 2-ELI002.00 BUOY RED 18 (CITY OF NORFOLK). Phosphorus improved at sixteen stations, none declined. Total suspended solids improved at 21 stations and declined at 12. The tabular statistical output can be viewed in the spreadsheet ESTUARY.XLS and the graphical output is available at: ESTUARY.pdf. The following maps show the annual loadings in pounds per year for each of the four water quality indicators:

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Figure 4.5-11 Estuarine Trend Map: Bacteria

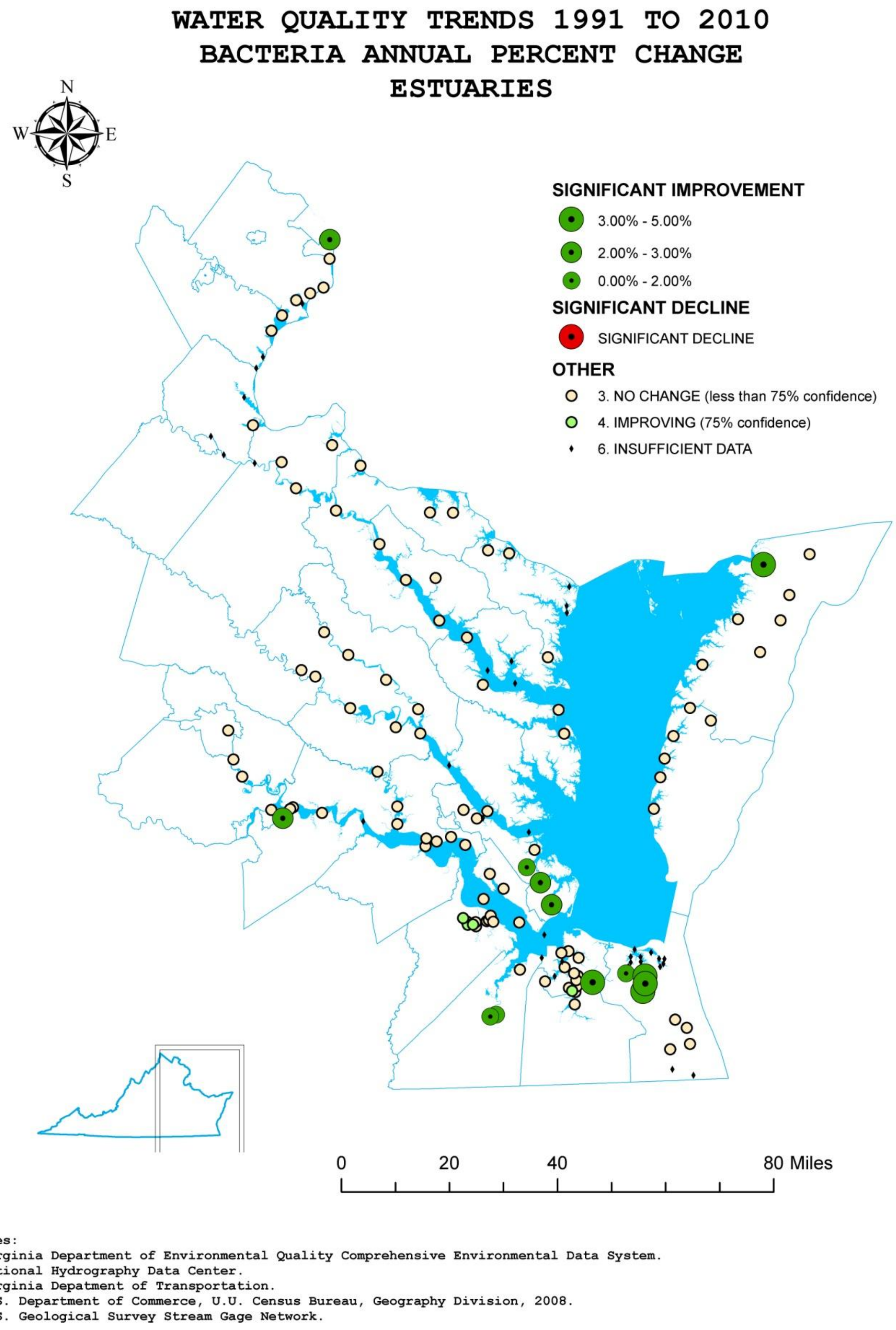
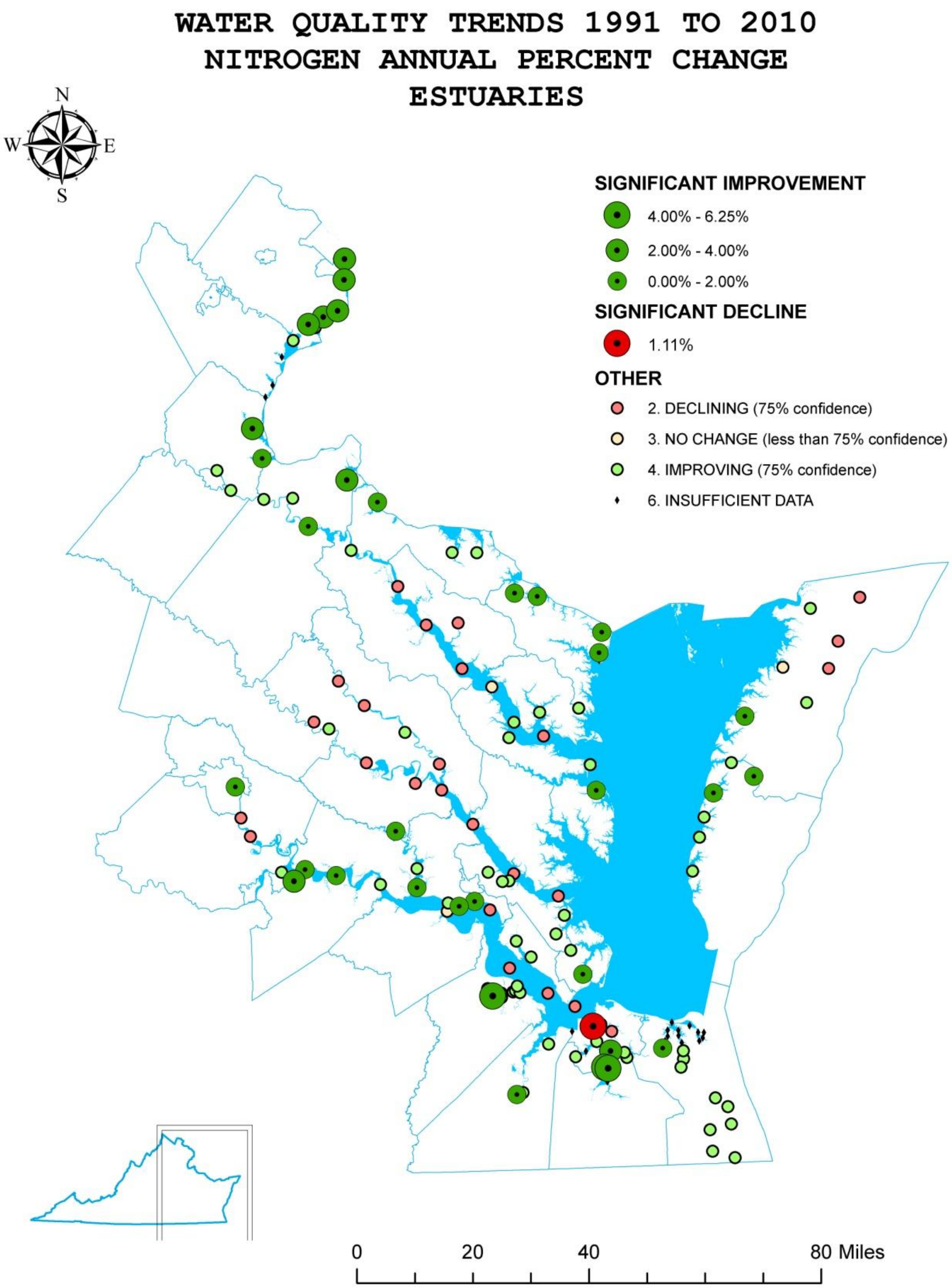
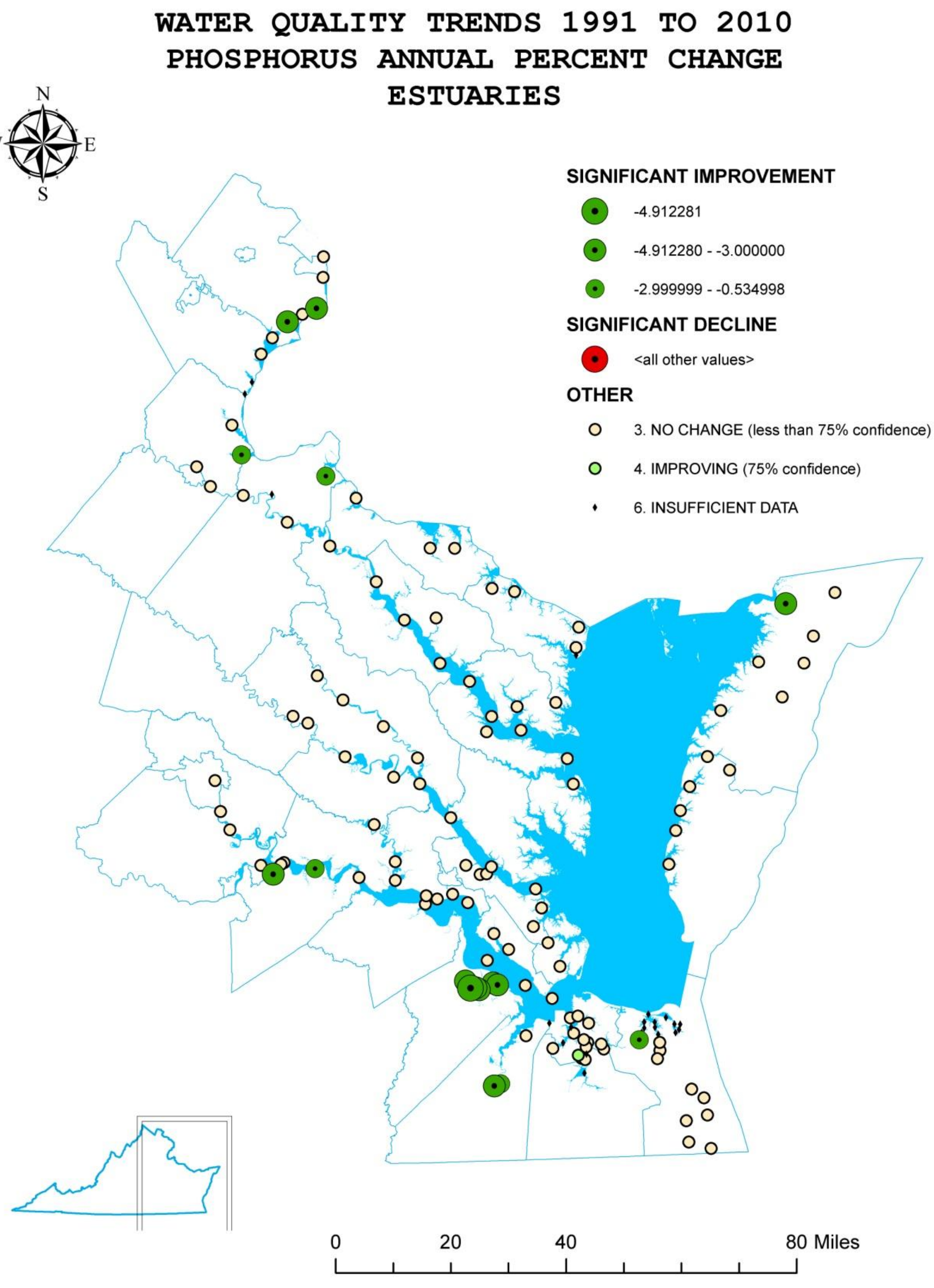


Figure 4.5-12 Estuarine Trend Map: Nitrogen



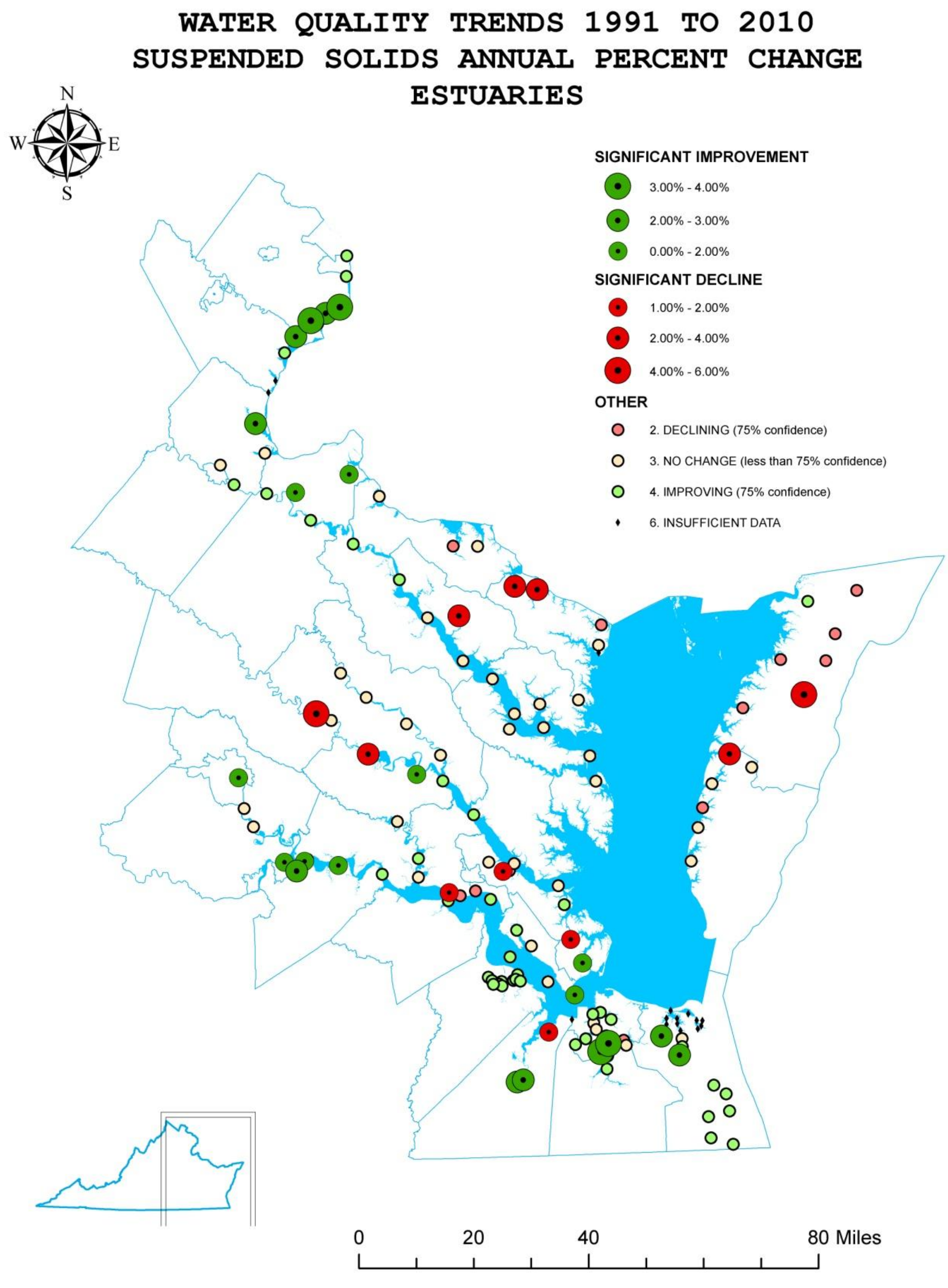
Sources:
1. Virginia Department of Environmental Quality Comprehensive Environmental Data System.
2. National Hydrography Data Center.
3. Virginia Depatment of Transportation.
4. U.S. Department of Commerce, U.U. Census Bureau, Geography Division, 2008.
5. U.S. Geological Survey Stream Gage Network.

Figure 4.5-13 Estuarine Trend Map: Phosphorus



Sources:
1. Virginia Department of Environmental Quality Comprehensive Environmental Data System.
2. National Hydrography Data Center.
3. Virginia Depatment of Transportation.
4. U.S. Department of Commerce, U.U. Census Bureau, Geography Division, 2008.
5. U.S. Geological Survey Stream Gage Network.

Figure 4.5-1 Estuarine Trend Map: Total Suspended Solids



Sources:
1. Virginia Department of Environmental Quality Comprehensive Environmental Data System.
2. National Hydrography Data Center.
3. Virginia Depatment of Transportation.
4. U.S. Department of Commerce, U.U. Census Bureau, Geography Division, 2008.
5. U.S. Geological Survey Stream Gage Network.

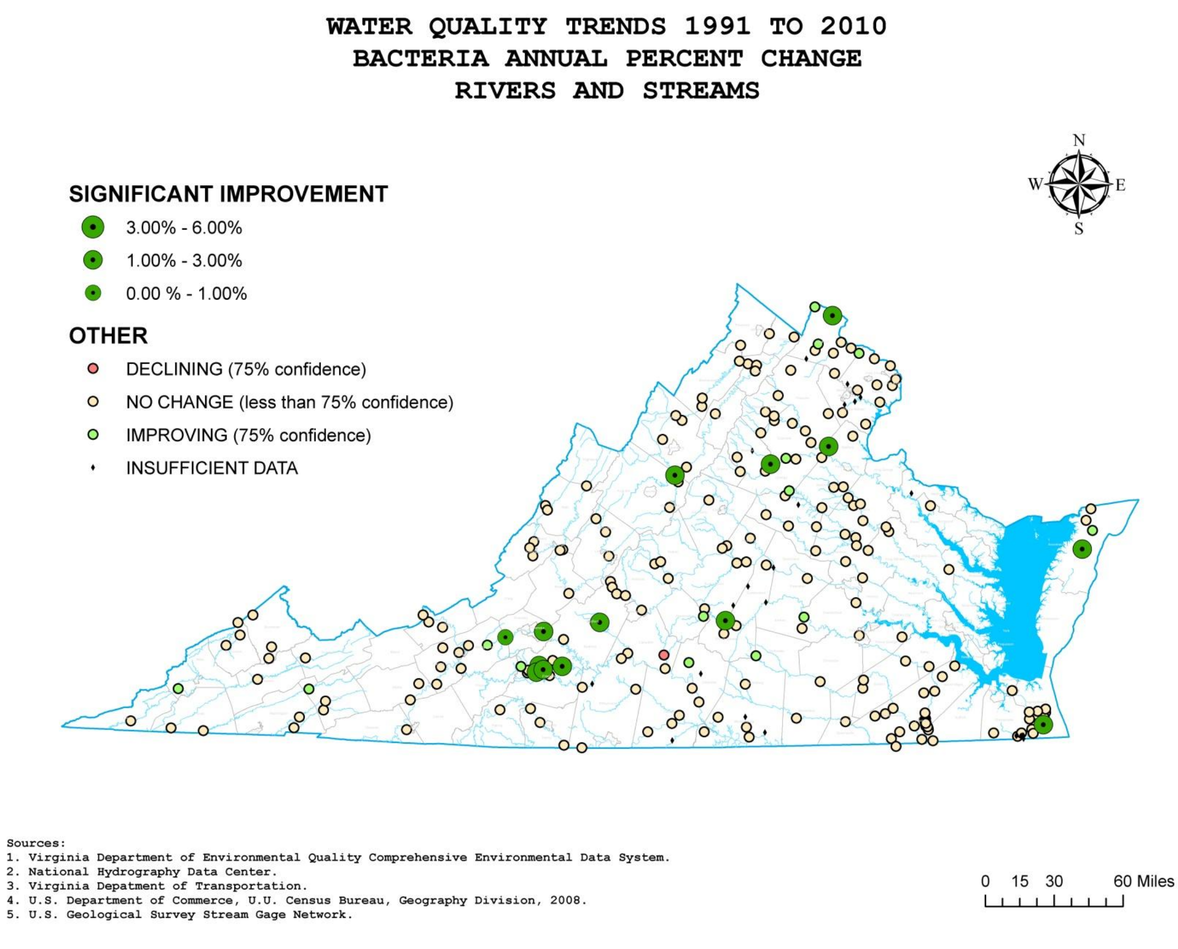
Rivers and Streams

There are 266 active trend stations including the stations collocated with gauges. The results presented in this section are not flow-corrected and are available at: [stream.xlsx]() and [STREAM.pdf]().

<u>Results</u>

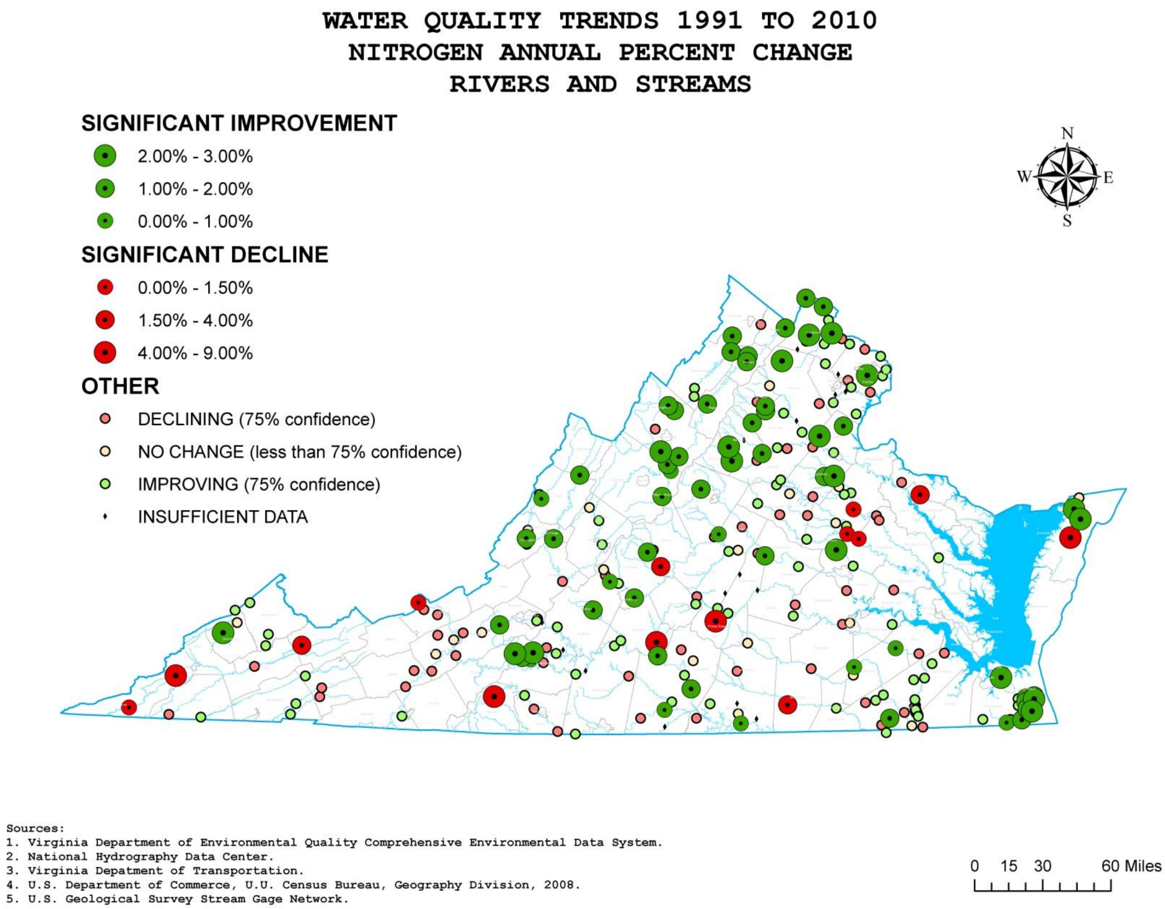
It is interesting to note that not a single station had a significant decline in water quality for bacteria while forty-five stations had significant improvements in water quality, see Figure 4.5-15. As reported earlier in this chapter there were no declining bacteria trends over the last twenty-years in any waters of the Commonwealth. This may point to the success of pollution measures, in addition to declines in discharge independent on management activities.

Figure 4.5-15 Rivers Trend Map: Bacteria



Nitrogen water quality has significantly improved at 67 stream and river stations and declined at 14, see Figure 4.5-16. Indeed, across all waterbody types nitrogen has improved at 103 stations, which is approximately twice the number of each of the other three indicator variables showing significant improvements.

Figure 4.5-16 Rivers Trend Map: Nitrogen



Phosphorus improved at 15 stations and declined at two stations (see Figures 4.5-17 and 4.5-18). Although the percent change per year is high at 173%, the baseline concentration is low with a slope of only 0.027 mg L/1 per year. At the current rate of change we can expect the average phosphorus concentration to increase by only 0.3 mg/L in ten years. Although the twenty-year trend at this station indicates increasing phosphorus concentrations, closer inspection of the green LOWESS trend line reveals that in the most recent short time period from 2007 to 2010 the phosphorus concentration was decreasing. This is an example of where a long-term trend is detected during a twenty-year period but there appears to be a change in trend direction towards improving water quality in most recent years. Inspection of all trend graphs is an important component in interpretation of changes over time. So in this example on Opequon Creek, even though phosphorus is increasing overall, water quality managers may want to allow for additional data before determining if the more recent downward trend is a better indicator.

Figure 4.5-17 Rivers Trend Map: Phosphorus

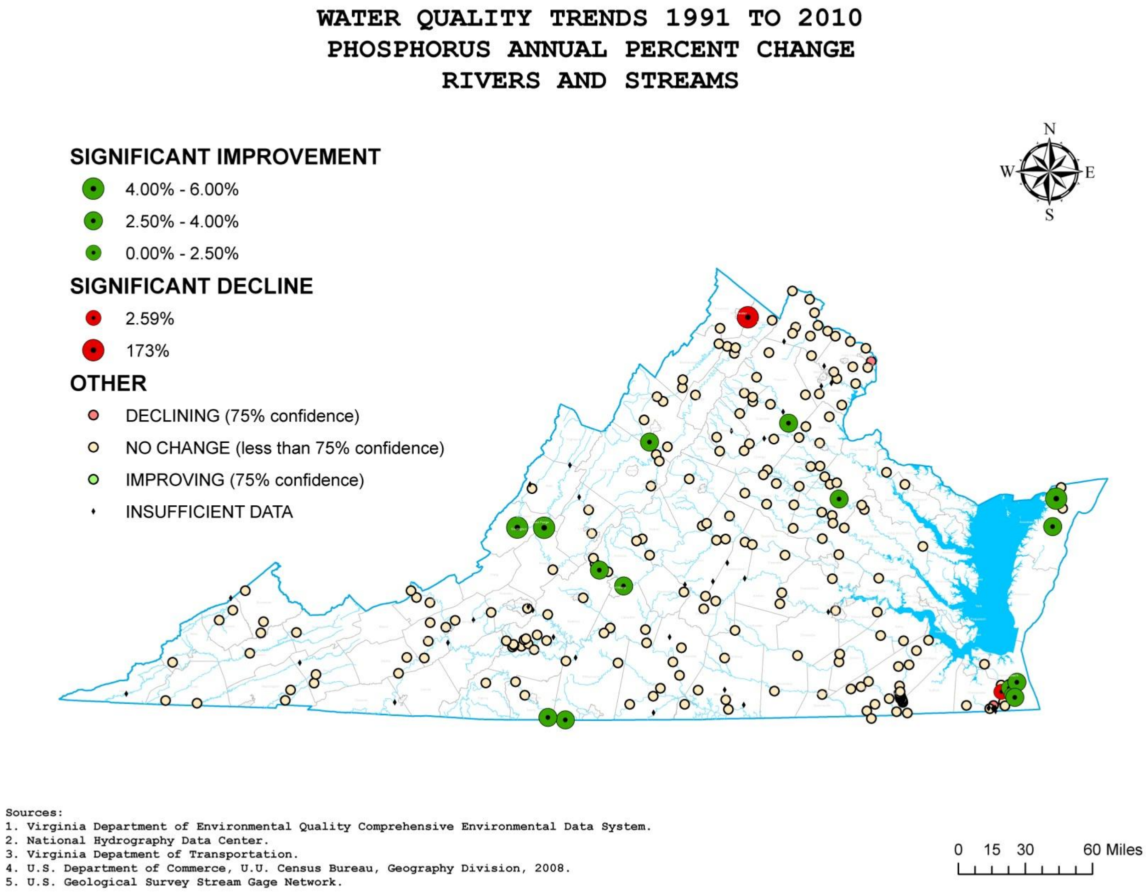
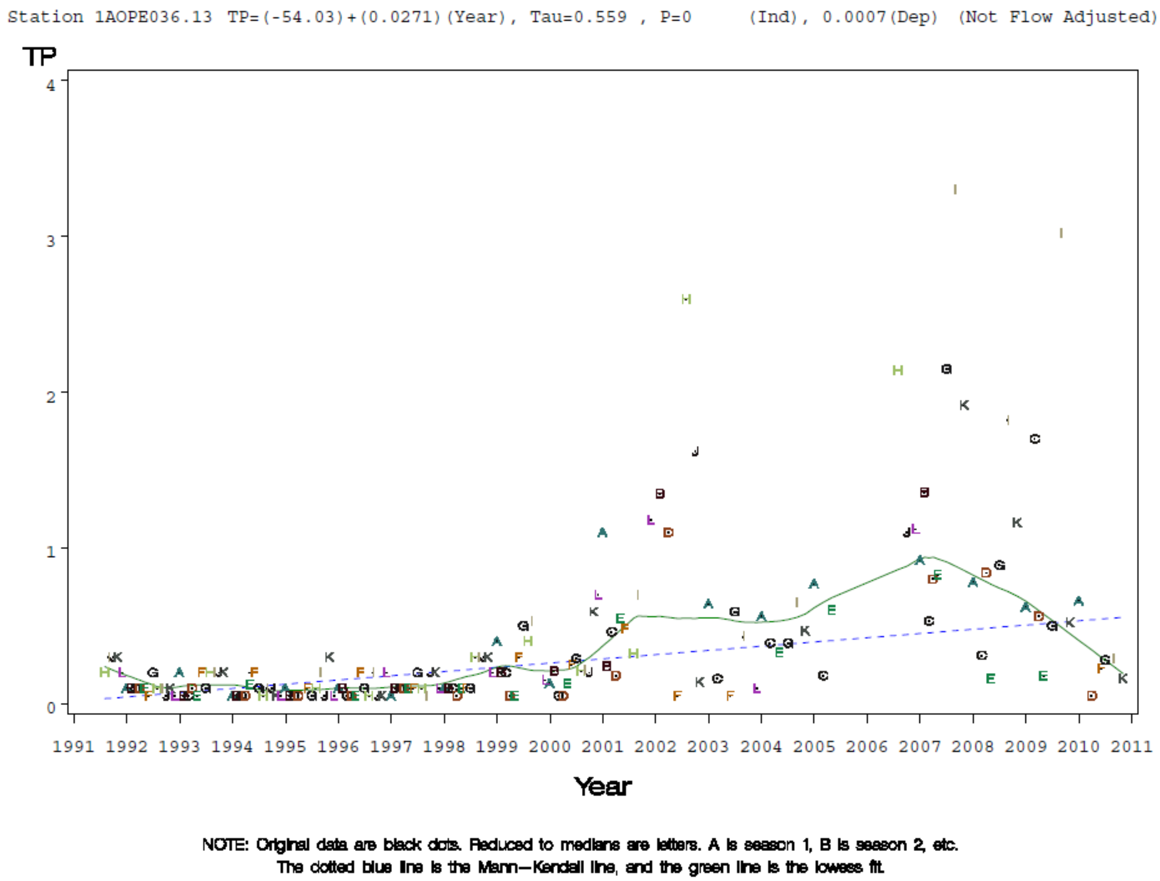
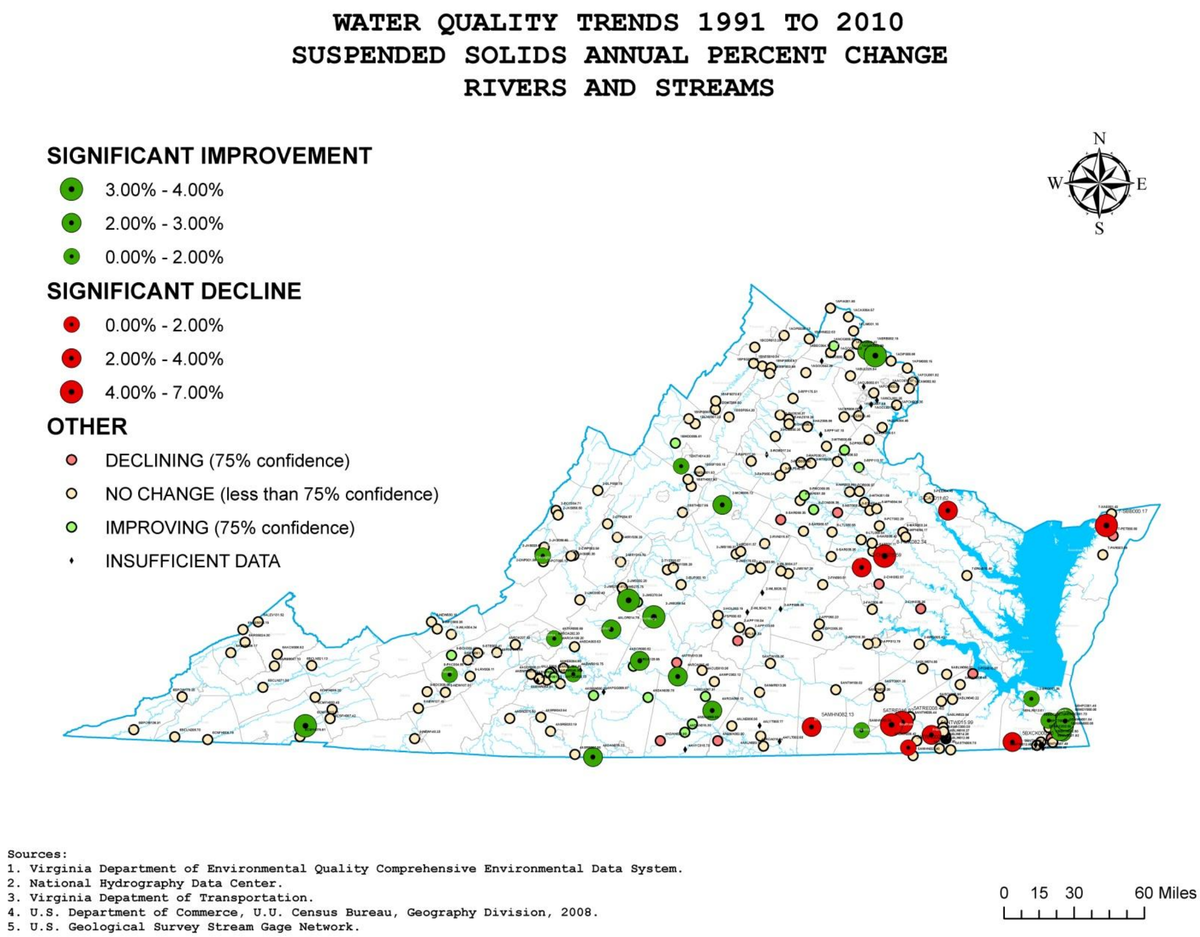


Figure 4.5-18 OPEQUON CREEK RT. 655 BRIDGE, FREDERICK COUNTY, 1AOPE036.13



Suspended sediment water quality improved at 26 stations and declined at 10 (see Figure 4.5-19).

Figure 4.5-19 Rivers Trend Map: Suspended Solids



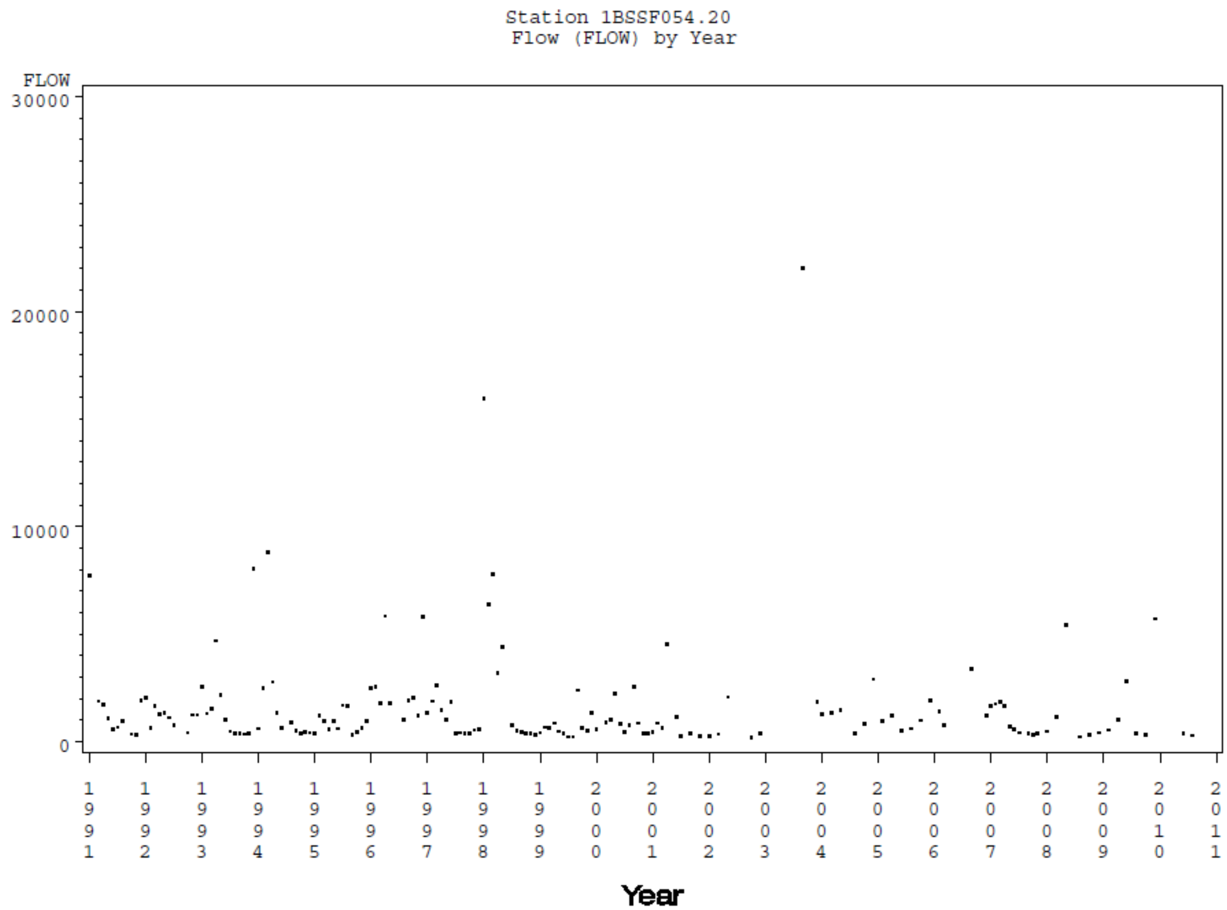
High resolution maps for all trend results stations can be viewed at: BACTERIA_MAP.pdf, NITROGEN_MAP.pdf, PHOSPHORUS_MAP.pdf, and SUSPENDED_SOLIDS_MAP.pdf. Where trends were determined on both flow adjusted and non flow adjusted data only the flow adjusted results appear on these maps as it is felt that flow correction provides a better trend prediction.

Loadings

In addition to analyzing for trends on flow-corrected concentration data, the modified seasonal Kendall analysis was performed on loadings. Individual water quality concentration measurements were converted to loadings in pounds by application of a unit conversion factor and then multiplied by the daily mean discharge as calculated from instantaneous flow. Nitrogen, phosphorus, and suspended solids were analyzed in this way. The purpose of such investigation is to determine the rate of change in pounds per year which is a more representative way to express trends in water quality. The full results can be viewed at: LOADS.pdf and loads.xlsx.

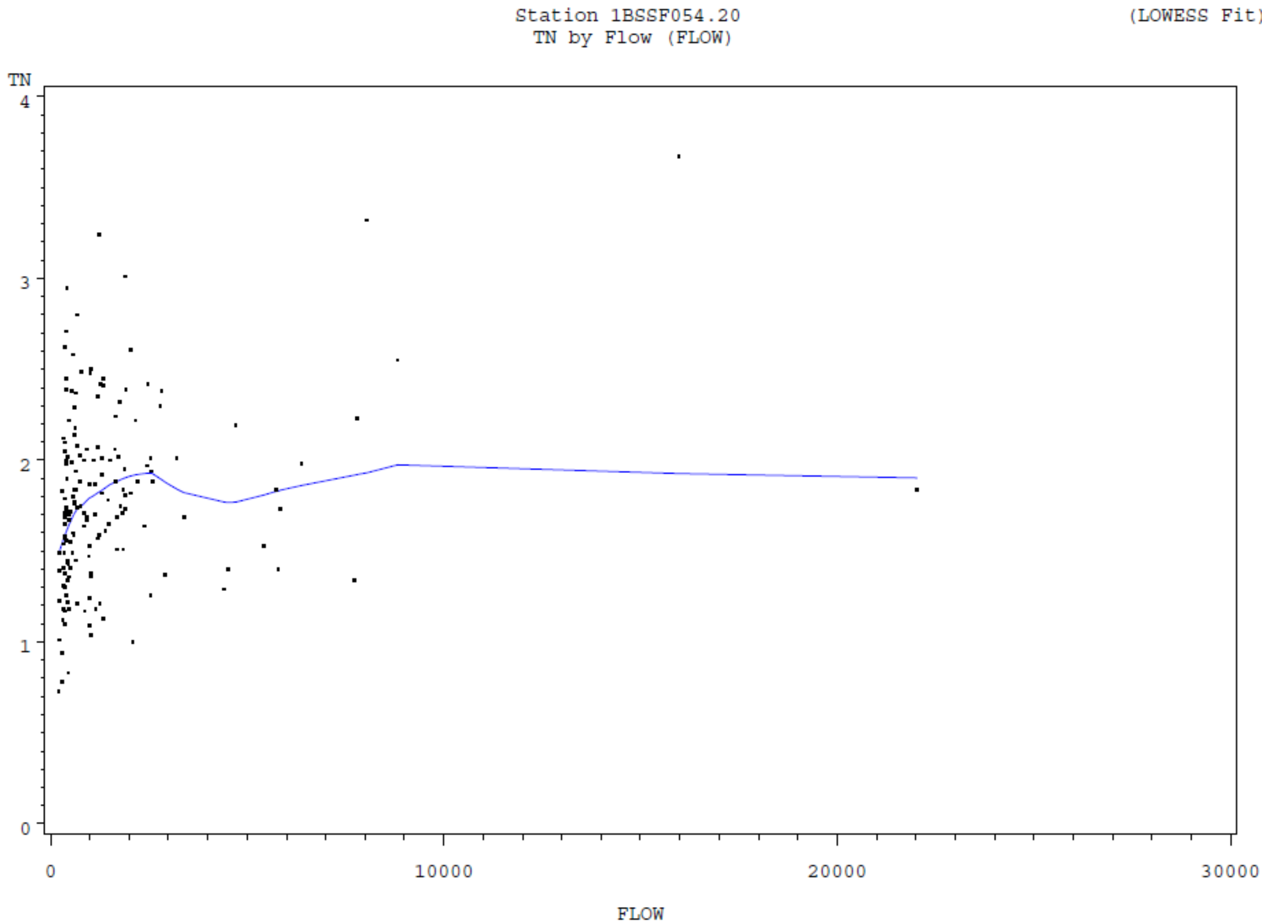
One of the outputs of WQ3 when running in the flow adjusted mode is a graphical representation of flow versus year (see Figure 4.5-20).

Figure 4.5-20 WQ3 Flow vs. Year



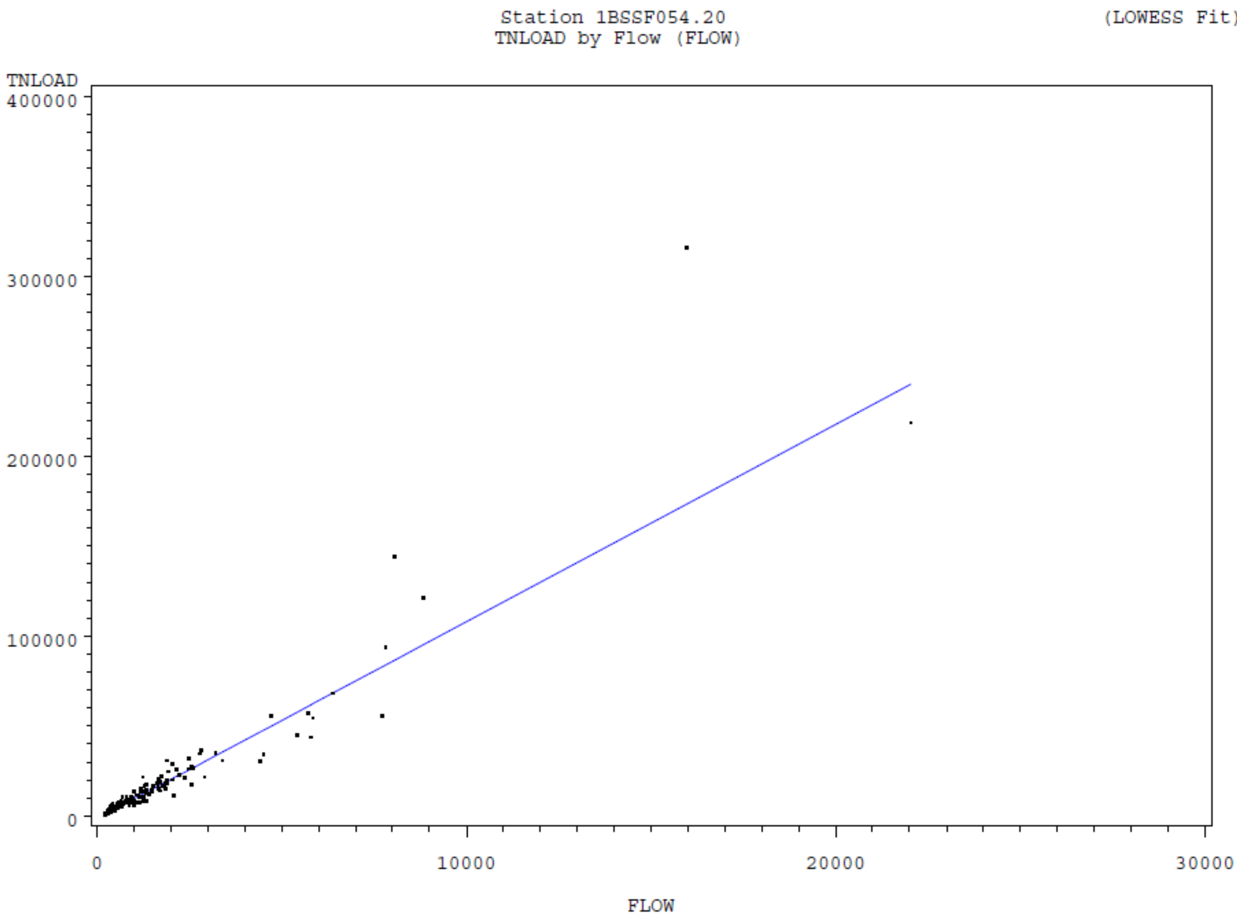
The next representation is the water quality variable concentration versus flow as seen in Figure 4.5-21. This example is concentration of nitrogen, mg/L versus flow, CFS.

Figure 4.5-21 Nitrogen vs. Flow



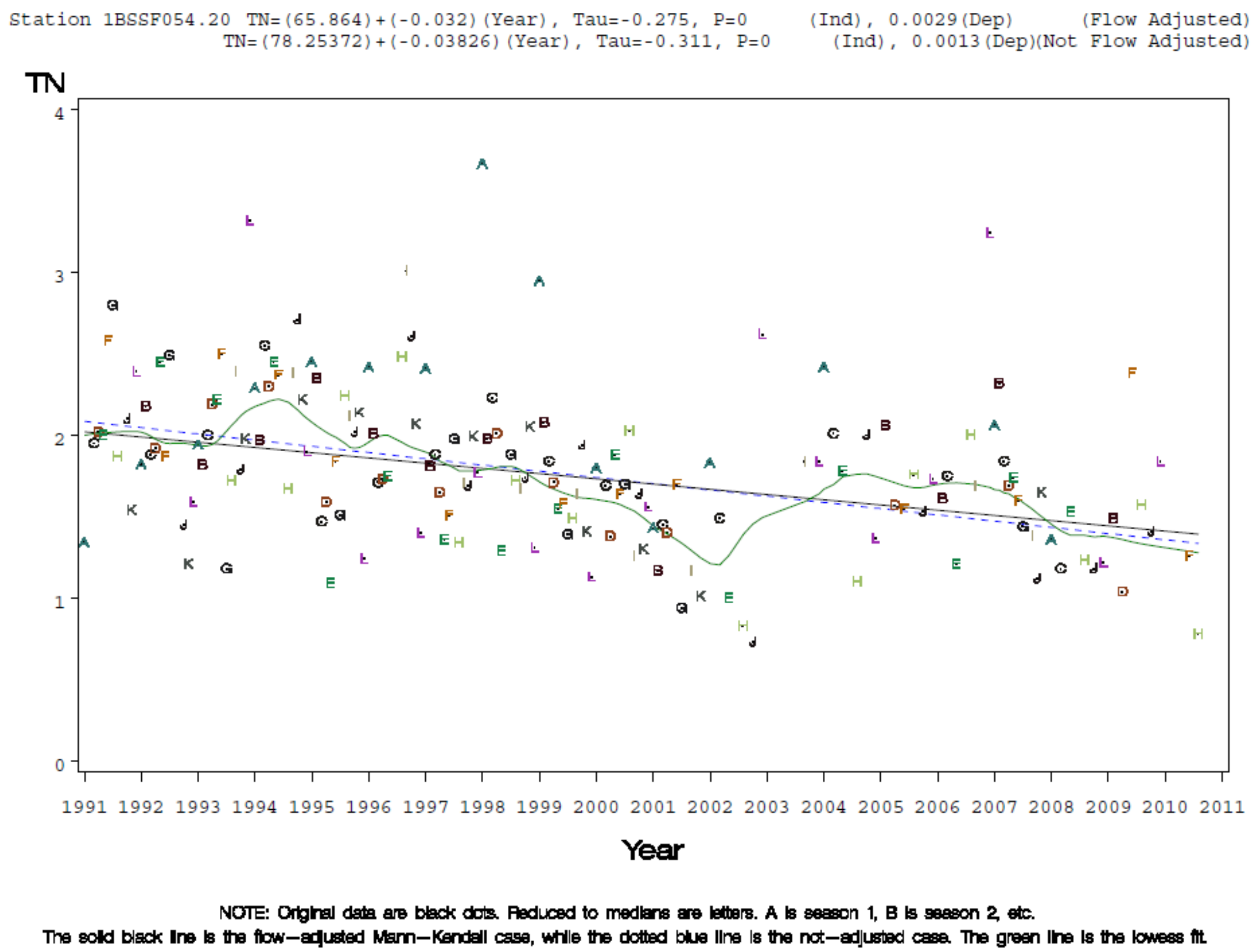
When the same data are converted from concentrations to loadings the relationship between load and flow is smoothed.

Figure 4.5-22   Nitrogen Load vs. Flow



The original flow and not flow adjusted trend results for nitrogen, mg/L, at 1BSSF054.20.

Figure 4.5-23 Nitrogen Concentration, Flow-Adjusted



The non-flow adjusted trend results for nitrogen, lbs per year, at 1BSSF054.20.

Figure 4.5-24 Nitrogen Trend in Loading

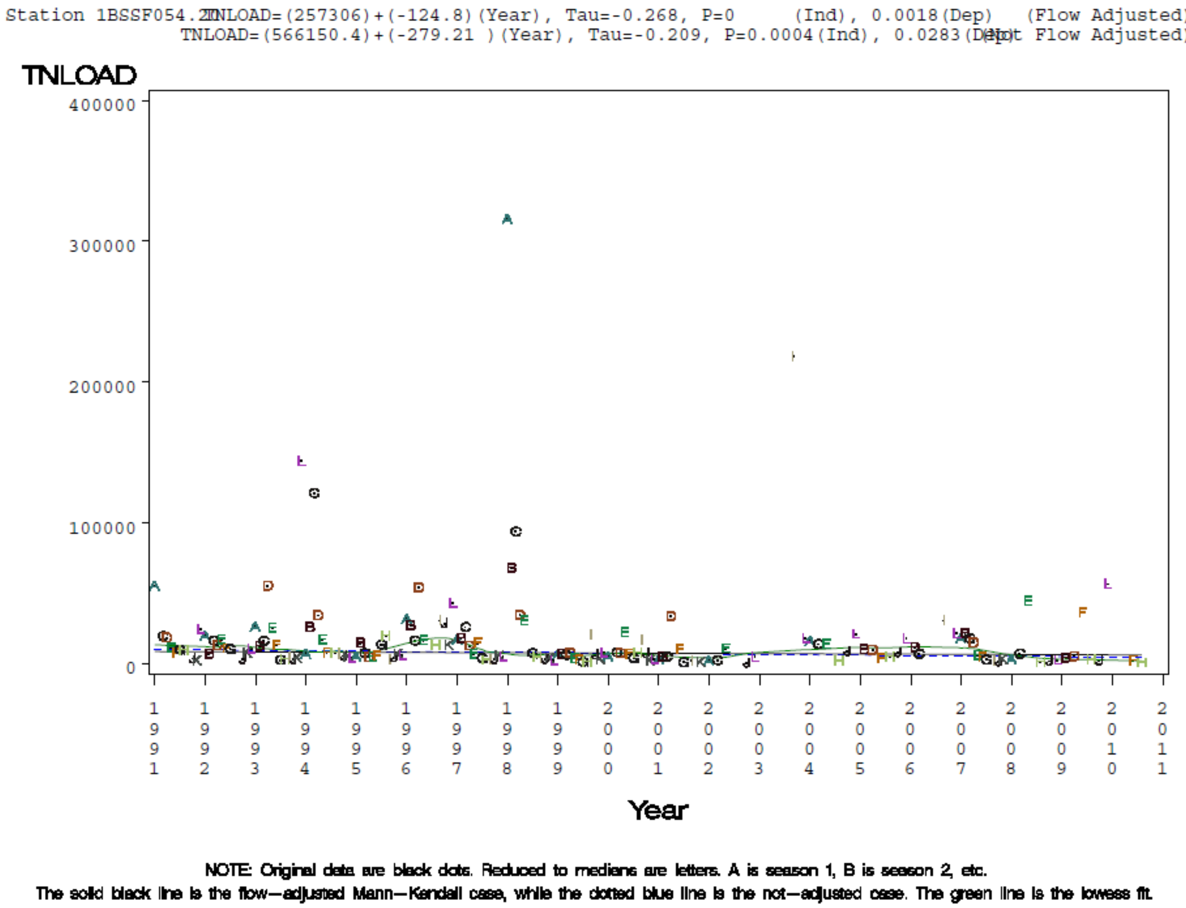


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Figure 4.5-25 Trends in Nitrogen, lbs per year

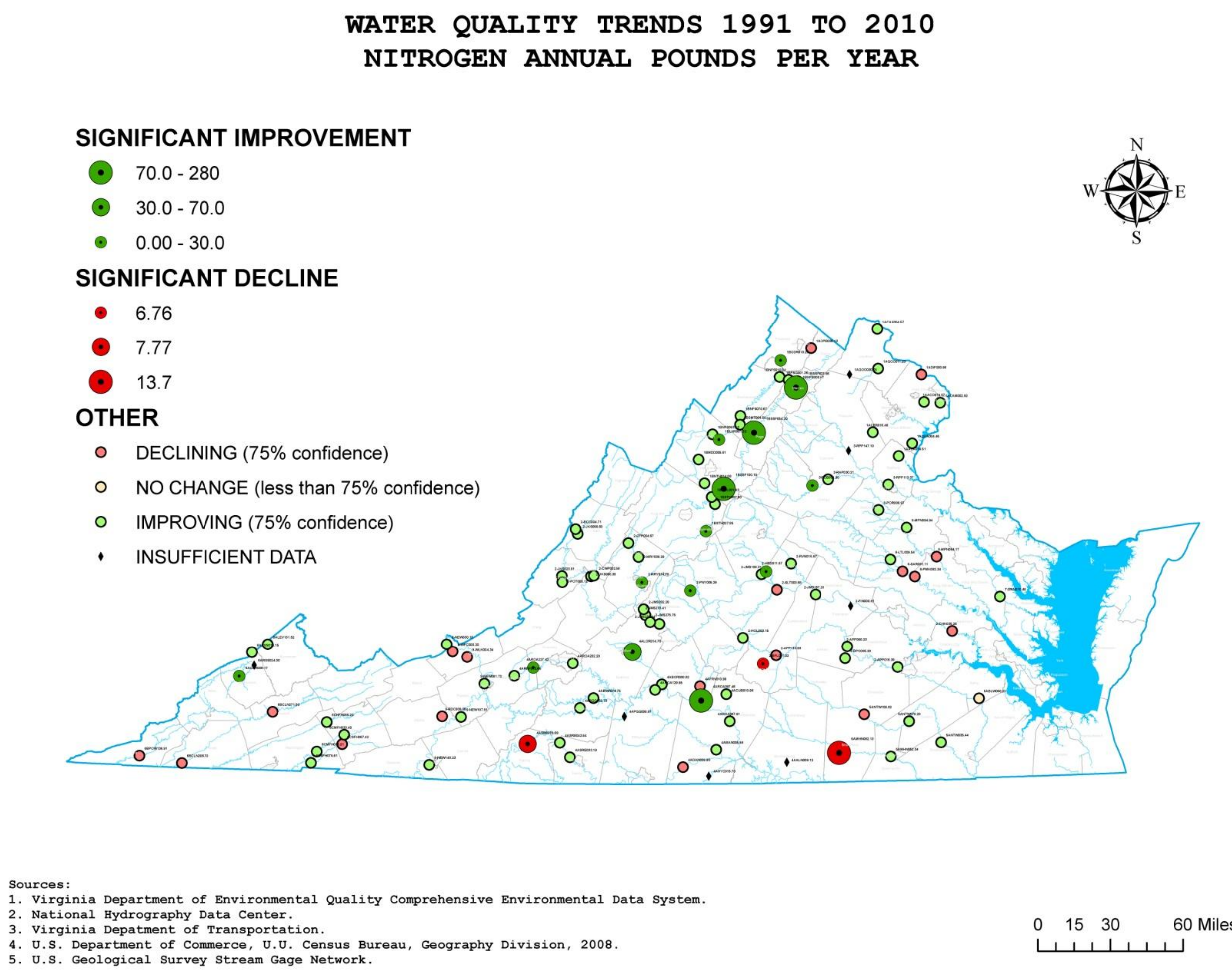


Figure 4.5-26 Annual Trends in Phosphorus, lbs per year

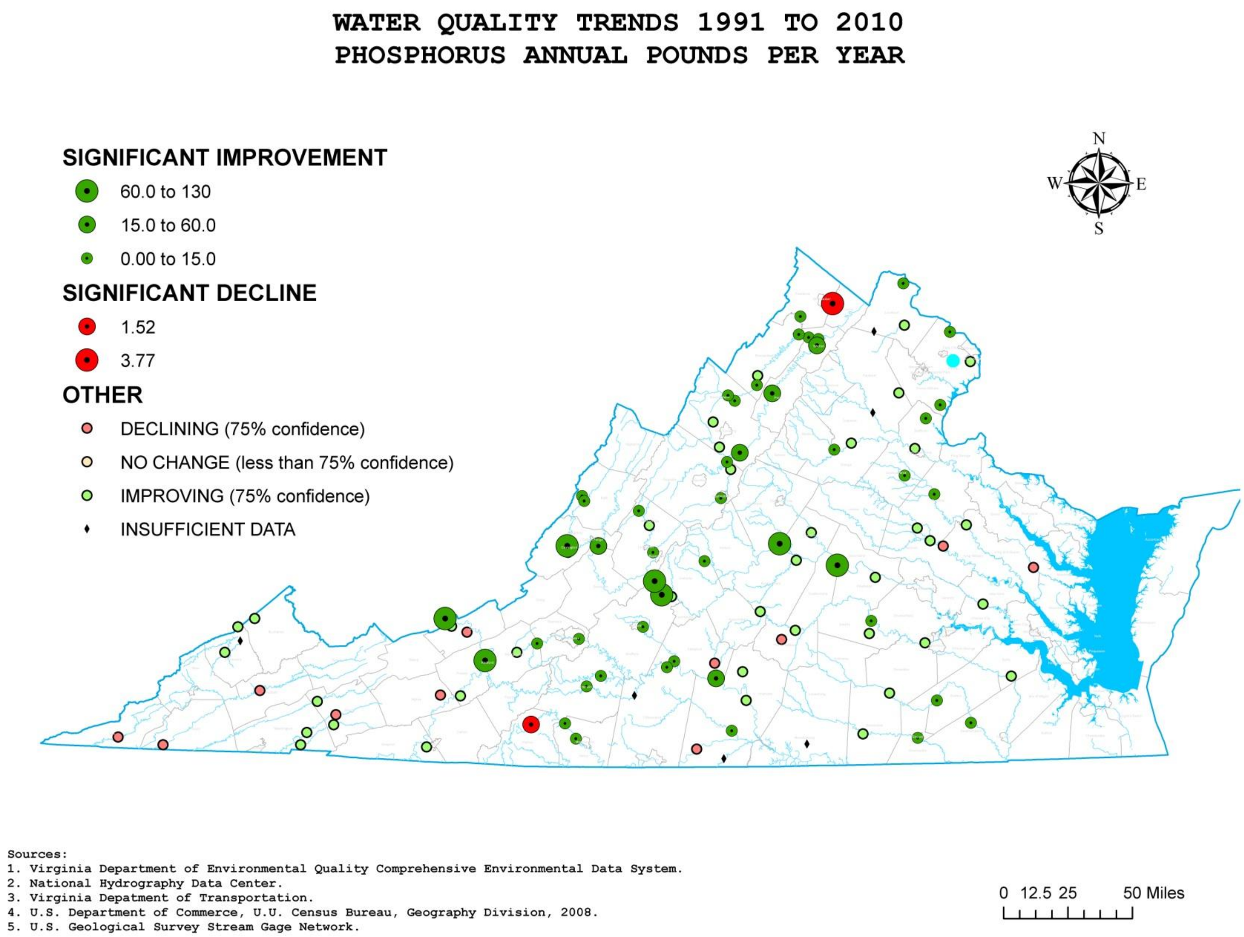
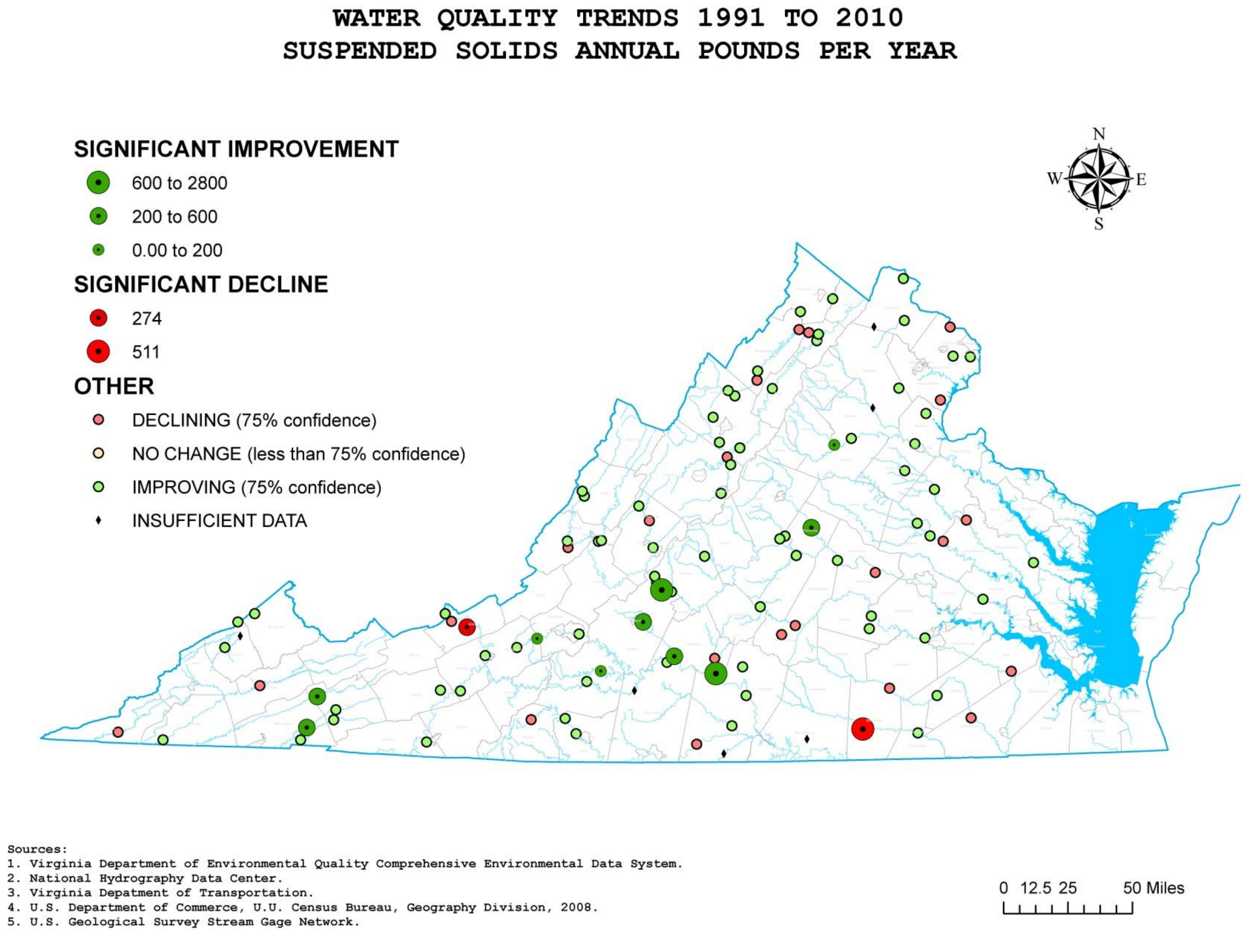


Figure 4.5-27 Trends in Suspended Solids, lbs per year

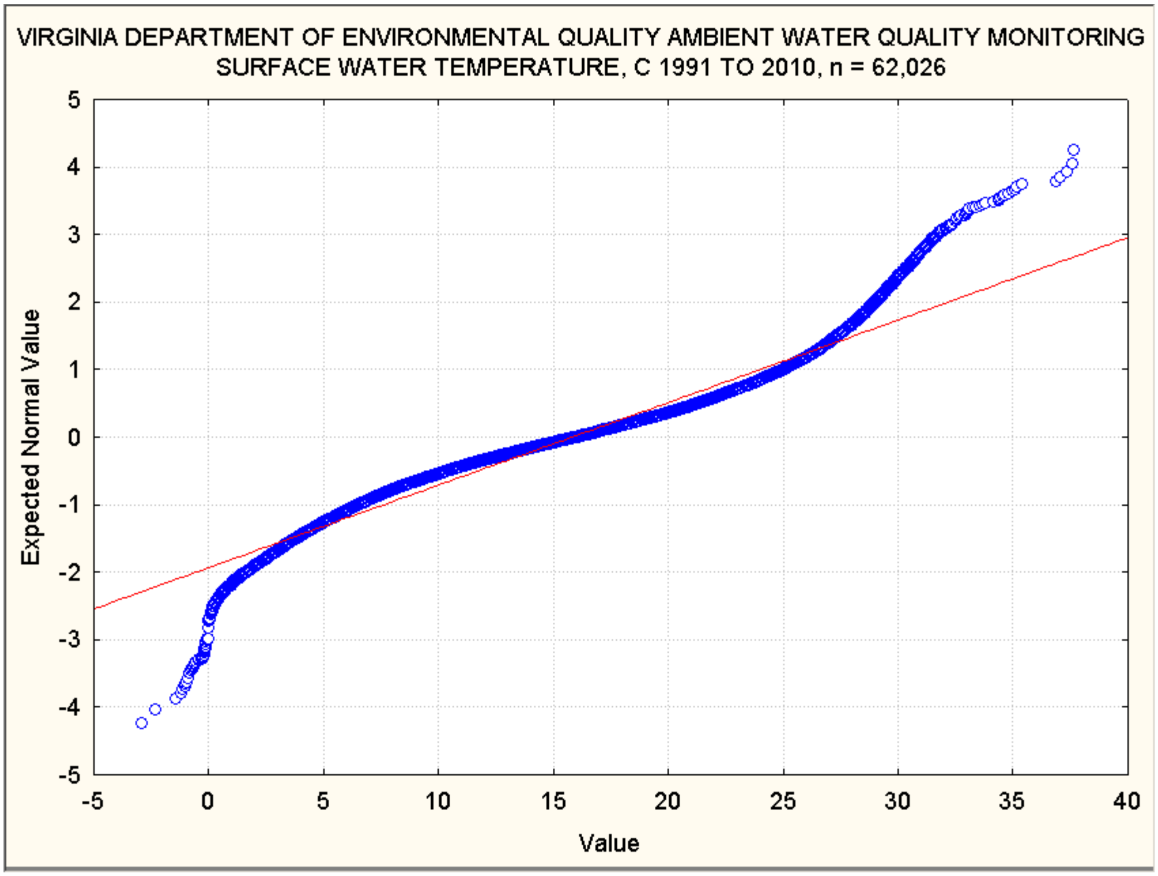


Surface Water Temperature

Surface water temperature (SWT), measured within the first two meters of water depth, is the most variable of all the long-term water quality parameters. SWT varies with several natural cycles including with diurnal, mensual, and annual fluctuations. SWT may vary by as much as several hundred percent in a diurnal cycle. Variability is also dependent on waterbody type, with estuaries tending to be less affected by extremes due to the mass of water present, whereas lower order streams can be greatly affected by daily solar cycles, canopy cover, stream morphology, and rainfall.

The normal probability distribution of all SWT measurements from 1991 to 2010 reveals a far from normal distribution, see Figure 4.5-28.

Figure 4.7-28 Normal probabiliy plot of surface water temperature.



The distribution of SWT among streams, reservoirs, and estuaries is significantly different as seen in Figures 4.5-29, 4.5-30, and 4.5-31. Streams and estuaries tend to exhibit distinct bimodal distributions whereas reservoirs have a flatter skewed distribution.

Figure 4.5-29 Histogram of stream surface water temperatures.

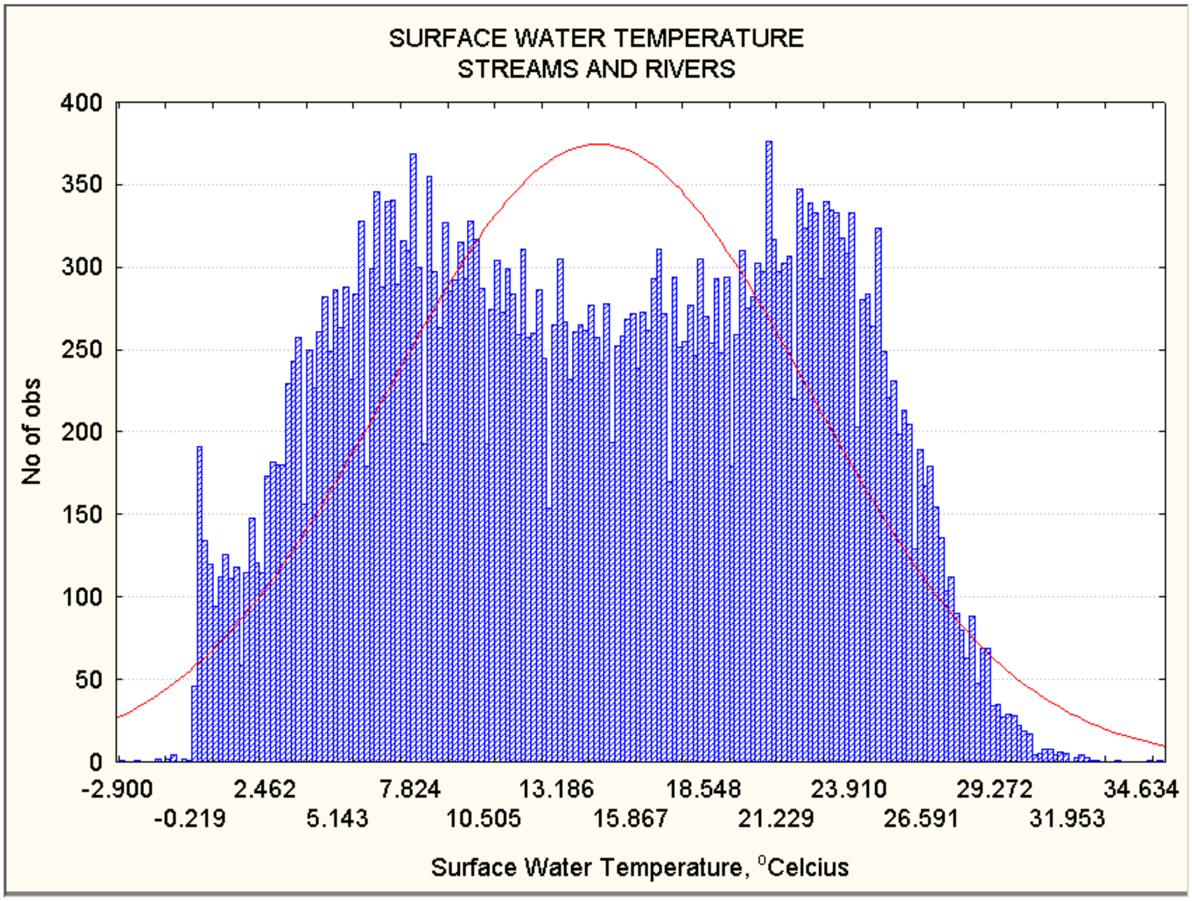


Figure 4.5-30 Histogram of reservoir surface water temperatures.

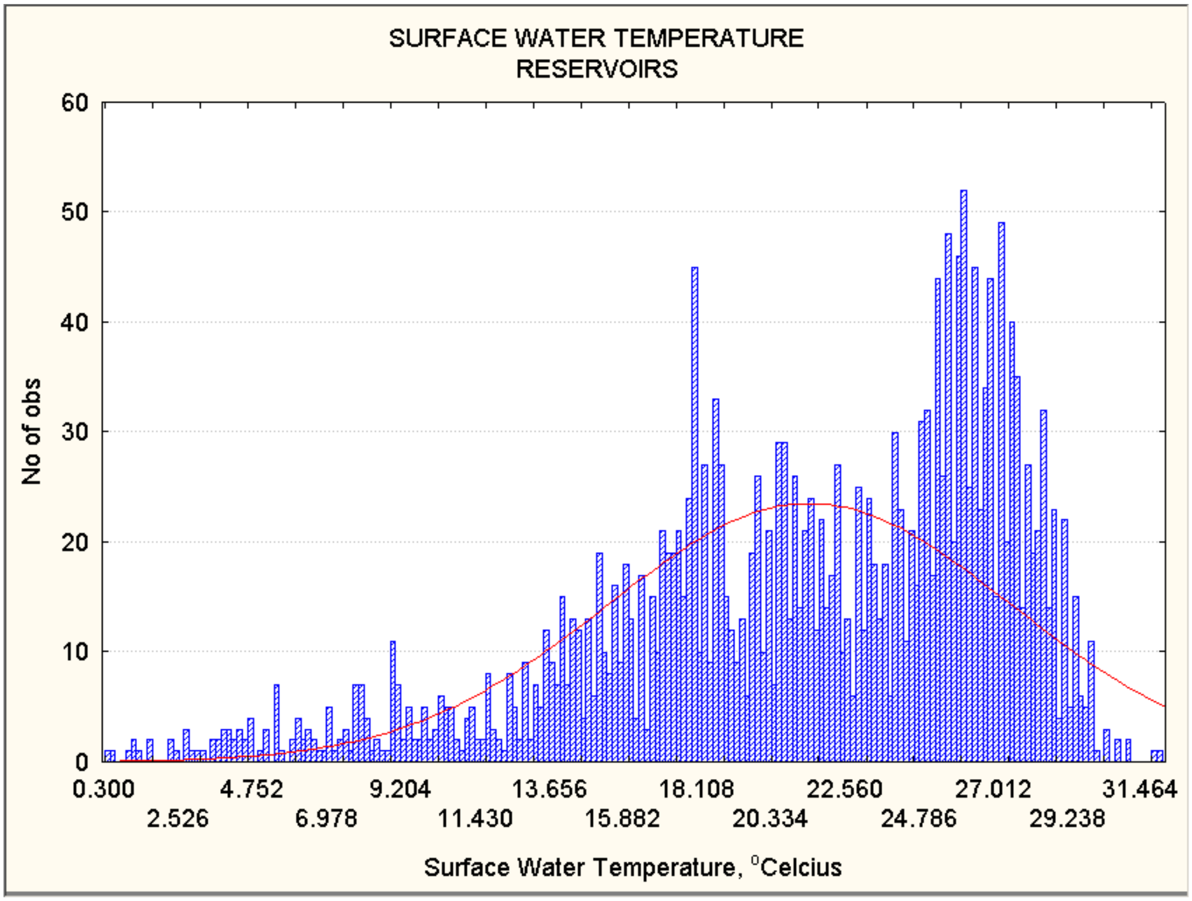
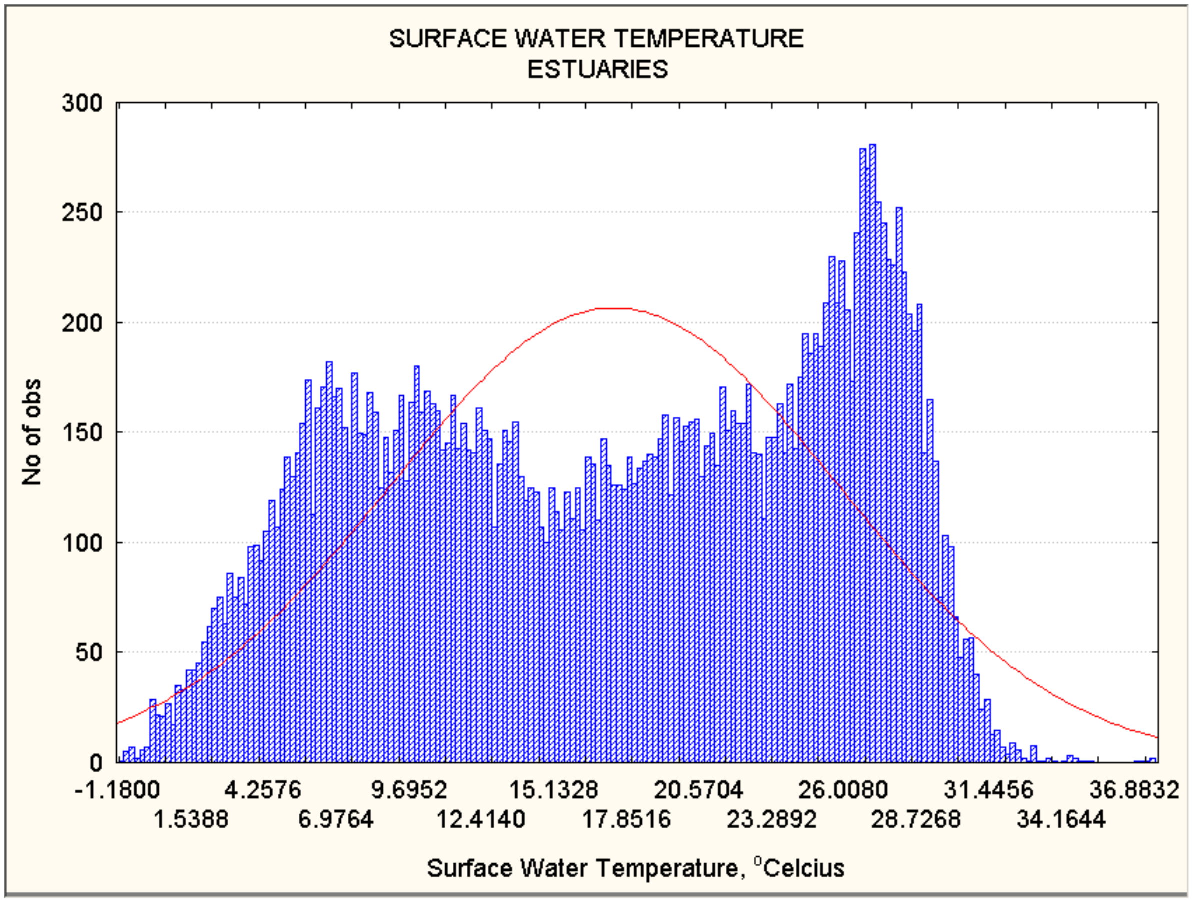


Figure 4.5-31 Histogram of estuarine surface water temperatures.



Nonparametric trend analysis of SWT measurements benefits from being a truly continuous variable without remark codes for detection limits and as such increases the likelihood of trend detection. SWT measurements are also numerous.

Long-term changes in water temperature can affect ecosystems with undesirable consequences. Our current understanding of global climate change is that local conditions may vary differently from the overall trend. Some areas will become warmer while others cool, and some local regions will experience increased rainfall while others become drier. Indeed, the statewide average annual rainfall over the last twenty years has been 8.3 inches greater than the average of the last one hundred and fifteen years.

The last time water temperature trends were reported[1] there was some concern about increases during the most ten years. Analysis of water temperature trends from 1991 to 2010 revealed no apparent statistically significant trends more than about what would be expected by random chance. Of the 401 stations monitored for long term changes in temperature 11% had significant increases in temperature and 4% showed declines, close to what would be considered random at the 90% confidence level. Temperature trends over the shorter period of the last ten years, 2001 to 2010, revealed even fewer

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[1] http://www.deq.virginia.gov/wqa/pdf/2006ir/2006irdoc/ir06_Pt2_Ch2.4_Trend_Anaylses.pdf

statistically significant trends with 3.3% increasing and 1.7% decreasing. The following two tables summarize the overall statistically significant twenty year water temperature trends and the individual monthly seasonal trends of the same data. It's interesting to note that August had the most number of significant trends, 30% more than the next closest month, with sixty stations warming and only two cooling. The statistical results can be viewed at: STREAM_TEMPERATURE.pdf, ESTUARY_TEMPERATURE.pdf, and LAKE_TEMPERATURE.pdf.

	YEAR_TRENDS
INCREASING TEMPERATURE, n	45
DECREASING TEMPERATURE, n	16
TOTAL NUMBER OF STATIONS	401
%INCREASING TEMPERATURE	11.2%
%DECREASING TEMPERATURE	4.0%

	INCREASING TEMPERATURE, n	%INCREASING TEMPERATURE	DECREASING TEMPERATURE, n	%DECREASING TEMPERATURE
JANUARY	23	5.7%	21	5.2%
FEBRUARY	10	2.5%	19	4.7%
MARCH	25	6.2%	23	5.7%
APRIL	25	6.2%	7	1.7%
MAY	2	0.5%	26	6.5%
JUNE	32	8.0%	10	2.5%
JULY	10	2.5%	32	8.0%
AUGUST	60	15.0%	2	0.5%
SEPTEMBER	24	6.0%	8	2.0%
OCTOBER	12	3.0%	7	1.7%
NOVEMBER	34	8.5%	12	3.0%
DECEMBER	2	0.5%	18	4.5%

APPENDIX SAS PROGRAMS

IMPORT_UV_FLOWS.SAS

MERGE_FLOW_DATA_FROM_MULTIPLE_GAUGES.SAS

FLOW.SAS

WQM_TREND_DATA.SAS

PRE_WQ3_DEQ.SAS

WQ3_DEQ.SAS

POST_PROCESSING_WQM_TREND_DATA.SAS